ON THE WATER RELATIONS OF THE COCONUT PALM (COCOS NUCIFERA)—ON THE OIL PRODUCED FROM THE NUTS—THE FACTORS ENTERING INTO THE RANCIDITY OF THE OIL, AND THE INSECTS ATTACKING THE TREES.

Introduction by PAUL C. FREER.

Investigations on the subject of the coconut palm (*Cocos nucifera*) have been carried on in the Bureau of Government Laboratories for the past eighteen months. The work has been divided into three parts and brought to its present state by coöperation between several divisions of the institution. It will be published in serial form in the JOURNAL. The first portion covers the water relations of the tree from the standpoint of its physiology, by Dr. Edwin Bingham Copeland, who spent several months on a plantation studying this question from an experimental standpoint. The second paper covers the coconut in its relation to the cultivation of the tree and the production of coconut oil, and includes a study of the deterioration both of the copra and the oil by reason of rancidity caused by molds and bacterial growth, by Herbert S. Walker; and in conclusion there is added a study of the insects which attack the plant, together with suggestions as to the best means of combating their depredations, by Charles S. Banks and William Schultze.

By this union of the laboratory work, the study of this most important tropical tree has been carried to an extent which not only will enable the conclusions to be of great value to planters but which will also have a scientific interest for those who are not immediately interested in coconut production. One topic which is of especial importance is still under investigation and not ready for publication. This is the study of the germinating nut together with the transformation which the oil undergoes during the growth of the embryo. This topic offers an opportunity for the study of the enzymes in a germinating plant which is unsurpassed, as the size of the seed of the coconut and the ease with which it is separated into its various constituent parts brings a certainty of results not to be encountered in other instances. This portion of the investigation is now being followed in the chemical laboratory. When the serial on the subjects mentioned above has been completed it will be published as a separate reprint.

San Ramon Government Farm, where most of these investigations were carried on, lies on the west coast of Mindanao 10 miles north of the town of Zamboanga. It extends for about 2 miles along the seacoast and toward the interior for 3 or 4 miles, to the base of a small range of densely wooded mountains, which forms an admirable watershed.

Four small streams run through San Ramon from the mountains to the sea. It is very probable that there is considerable underground drainage as well, for fresh water may be obtained at a depth of 5 or 6 feet almost anywhere along the shore, even at the edge of the beach. At present copra and hemp are the principal products of the farm, together with a little cacao.

At the time of writing all the coconut trees used for making copra at San Ramon were planted by the Spanish, but large numbers of new ones are being set every year from selected seed, for which only the largest and best nuts are taken. They are laid out on the ground in a sheltered place and a small section of husk is cut from the top of each to afford a more easy egress for the sprout. At the end of about six months' time, when the sprout is from 2 to 3 feet high and the nut has just begun to take root in the ground, it is ready for planting. For this purpose a hole about 2 feet deep is prepared and the young plant is firmly packed with the soil, so that the sprout stands erect and the top of the nut is 6 to 10 inches below the surface. As a protection against wild hogs it has of late been the custom to dig a pit 4 or 5 feet deep and to plant the nuts at the bottom of this. The seedlings are set out in straight rows, allowing a space of about 10 meters between each plant.

After planting, the young coconut requires very little care, except to keep it free from weeds and the attacks of animals and insects, until it reaches maturity. The average time before a tree begins to give a good yield of fruit may be set at ten years. Instances have been known when bearing commenced as early as the fifth year, but these are of rare occurrences and under exceptionally favorable circumstances.

The process in use for preparing copra is very simple. The nuts are gathered by natives, who climb the trees, cut off the ripe or nearly ripe fruit, and let it fall to the ground. No especial care is taken to prevent damage by falling. The nuts are then piled in a heap and allowed to stand for a few weeks before being opened. To remove the outer, fibrous husk the natives make use of a heavy spearhead firmly sunk in the ground. They force the nut down on the sharp point until it penetrates to the shell, then, by a peculiar twist, strip off the husk, a portion at a time. One man can husk, on an average, 1,000 nuts per day.

After being thus prepared the coconuts are split in halves by a couple of sharp blows from the back of a bolo. The milk is allowed to go to waste on the ground.

Drying.—The simplest method of drying the meat is to spread out the halves of the coconut on large wooden trays, face up, in the sun. At

night and in case of rain the trays are piled under a shed. After standing in the sun for two or three days the meat becomes partially dry and has shrunken sufficiently to permit its removal from the shell. It is then put back on the trays and again exposed for a few days until it is thoroughly desiccated.

The other method of preparing copra in use at San Ramon is to pile the coconut halves, face downward, on a bamboo grating over a slow fire of husks which is burning in a thick-walled brick kiln about 6 feet high, the whole being inclosed in a large shed. By this arrangement it is sufficient to dry the nuts over night before removing the shells.

After heating the meat in the same manner during four or five hours on the next day, it is ready to store for the market. "Grill-dried" copra prepared in this way is not quite so liable to be attacked by insects and molds, but on account of its dark color and slightly smoky flavor it is considered inferior in quality to the sun-dried article.

ON THE WATER RELATIONS OF THE COCONUT PALM (COCOS NUCIFERA).

By Edwin Bingham Copeland.

(*From the Botanical Section of the Biological Laboratory, Bureau of Science.*)

The work on *Cocos nucifera* (coconut), the result of which is reported below, was performed at the Government farm at San Ramon, near Zamboanga. Its purpose was to acquire as thorough a knowledge of the physiology of this palm as the field conditions would permit, with the especial hope that the results would be available for improving existing methods of the plant's cultivation.

Because of the remoteness of the place of work from any library or base of supplies, the simplicity of apparatus which for the greater part is used in investigating all phases of a plant's transpiration, the writer's familiarity with this particular field, obtained in the preparation of earlier papers, and because of the very great practical importance of understanding this phase of the physiology of any plant important in agriculture, the work was principally focused on the water relations of the coconut. At the same time other phases of the tree's activity were not neglected; and, in cases where it seemed worth while, notes not bearing on the main subject are included in this paper. The value of artificial or natural fertilizers was not considered, because this question is more in the domain of the agriculturalist.

The divisions of the main subject are treated in the following order: The root—its structure and growth, and the absorption of water; the leaf—its structure, the activity of the stomata, and the transpiration; with final conclusions as to the fitness of the plant for its characteristic habitat and suggestions as to its most advantageous cultivation.

THE ROOT.

The roots of *Cocos nucifera* have the two typical root functions—the anchoring of the tree and the absorption of the water and mineral food necessary for its maintenance and growth. In the absence of a taproot, or of any great roots the hold of which in the ground can maintain the rigidity of the trunk, the mechanical problem of the firm anchorage of the latter finds a solution essentially different from that which we are accustomed to encounter in the case of dicotyledonous trees. The base of

the trunk is convex or obconical, and is usually buried for a depth of hardly more than 50 centimeters. Its surface underground is almost entirely covered with the bases of the roots. The latter are remarkably uniform, about 1 centimeter in diameter, radiating from the tree on all sides, each without much variation in its direction, and, so far as my observations justify a general conclusion, for a normal distance of about 5 meters in firm soil and 7 meters in sand. The lateral branches, whatever direction they may take with regard to the action of gravity, leave the main roots with surprisingly uniform exactness at right angles and are likewise on the whole straight, though less so in detail than the main roots.

The old main roots are notable for the combination of elasticity [1] and tensile strength shown by their powerful central steles, the cylinder of xylem inclosing a "pith" with thick, lignified walls. The most conspicuous feature of the branches is their stiffness, for which the stele is not more responsible than the hypodermis. I have never before, in any plant, seen a rigidity on the part of the fine, absorbing roots which will compare with that possessed by those of the coconut. The intimate contact between the hard, firm roots and the soil is responsible for the rigidity of the *Cocos,* as of other trees, but while in most, this contact is centered about the base of the trunk, the *Cocos* has it disseminated equally through the ground to a radius of 5 meters or more. The main roots act as so many taut strands between the base of the trunk and the multitude of fine points of attachment. The effectiveness of the coconut's system of anchorage is perfect. The tree's favorite habitat is the seashore, where it receives the unbroken force of the fiercest storms. Because of its elasticity, the trunk very rarely breaks, and I have never seen one instance of an uprooted coconut, the roots of which had not either previously been killed or undermined by waves.

Eighty centimeters is not a very exceptional diameter for a well-grown bole, though a majority fall below this size. The buried part of a stem of this thickness will afford attachment for nearly 8,000 bases of roots 1 centimeter in diameter. Some of the main roots bear few or no branches at all like themselves; others have 10 to 20, which rarely reach a length of 1 meter or a diameter of 4 millimeters. The main roots and these major branches bear numerous fine ones, 1 to 2 millimeters in diameter, springing forth at right angles and having a rigidity which has already been noted. These may be the ultimate divisions; or they in turn may bear finer branches, at most a very few centimeters long, about 0.5 millimeter in diameter; the life of the latter is transitory like that of root hairs. A less ample system of branches is formed in sand than in firmer ground.

Dead, distal parts of roots are replaced from the bases of the same roots

[1] Pfeffer, *Pflanzenphysiologie*, II, page 60, cites Sonntag, *Landw. Jahrb.* (1892), **21**, 839 as authority for a stretching of 20 per cent by *Cocos* fibers, without exceeding their limit of elasticity.

in such a way that the new takes the place of the old, not only as an absorbing organ but in the mechanical system as well. At the point where dying back ceases, a root, or frequently two roots, spring from the end of the part which is still living. Their origin apparently is internal, and, as is to be expected, from the outer limit of the stele; the hypodermis of these older parts of old roots is so strong that the young ones are rarely able to break through it, with the result that they grow onward within the shell, sometimes for 30 centimeters or more, before the hypodermis is sufficiently decomposed to permit their escape. The direction of growth is then well fixed. From an observation of exceptional cases in which the young root succeeded in rupturing the hypodermis at its origin, and in which it then grew along or near it, it appears that as a phenomenon of "correlation" the young root has the same orientation-reaction as the one it replaces. The old hypodermal shell is a most effective aid in this reaction.

My observations on the rapidity of the growth of roots have been unsatisfactory. Many times I have marked off zones on apparently healthy roots only to discover that they showed no subsequent growth. Some, for a time, have elongated little or not at all, then for a few days have grown vigorously, then stopped, without any apparent reason for the irregularity:

The most rapid growth I have measured was 3.5 millimeters per diem. In a month three roots grew more than 4 centimeters, but none as much as 5 centimeters. Sometimes, under favorable conditions, there may be a much more rapid growth than I have been able to observe; 3.5 millimeters per diem is hardly more than 1 meter per annum, a rate too slow to be accepted without more evidence. A part of the roots I examined grew in water and a part in air surrounded by soil. Those which elongated considerably in water at the same time became more slender.

In large and rapidly growing roots a little elongation occurs in a zone 10 to 15 millimeters from the tip (not from the growing point), but in most cases it is confined to the apical 10 millimeters. The root whose growth was most rapid was 9 millimeters in diameter and had a cap 10 to 11 millimeters long. In two days the latter grew 0.5 millimeter, 5 millimeters of root grew out of it, and the zone immediately outside grew 1.5 millimeters. The length of the cap is somewhat greater than the diameter of the root, which is usually about equal to the length of the growing zone when measured from the outside tip; therefore all growth is generally within the cap. In this case the cap grew one-tenth as rapidly as the root, and this seems to be about the usual ratio. In the ground the resistance to the passage of the moving tip results in a continual tearing off of the outer layers of the cap, these layers usually persist in the form of collars around the root, and each is about as long as the cap; altogether they not infrequently form a sheath along the whole younger part of the root. It is possible that these collars or sheaths facilitate the absorption of water. When the root grows without friction, in water, the whole outer portion of the cap, while retaining its form, is occasionally sloughed off.

No response to any other directive agent is so conspicuous as the autotropism of the coconut roots, of whatever order. The general level of the main roots is maintained by a combination of hydrotropism and aërotropism, which I have not

been able to analyze. A recent paper by Bennett[2] shows that many cases, at least, of apparent aërotropism are really hydrotropic, and the same is probably true with the *Cocos*. The roots maintain a deeper level in sand than in heavy soil. When the other stimuli are removed, a variable geotropism shows itself; some, in water, grow straight ahead in as nearly horizontal a direction as it was convenient to arrange them in the bottle; but the majority show a feeble positive geotropism, the most rapidly executed curve being 40° in two days. The secondary roots are usually controlled by their autotropism alone. In heavy soil they are sometimes more numerous on the upper sides of the main roots, probably because of an induced geoauxesis, since the structure of the roots precludes the probability of any direct locative influence of moisture on their origin, and the pneumathode roots appear on all sides. In nature, no roots will grow to any distance into water, nor into a level of the soil where water stands; and a rise in the water level ultimately kills the submerged ones.

Root structures.—The stelar tissues of the coconut root offer very little that needs description. The number of xylem rays is usually 40 or more in the larger, 10 to 15 in the branch roots, 1 to 1.5 millimeters in diameter, and fewer in the finer ones. In the young parts of the main ones the pith is parenchymatous, with very thin walls. The latter begin to thicken at a distance from the apex at which both hypodermis and endodermis have reached their permanent state. They then become very thick throughout, and are the chief source of the root's great tensile strength.

In cross sections, a very few cells behind the growing point, the pericycle is distinguishable by the regularity and the large size of its cells. The latter eventually become somewhat flattened tangentially, but they still form a conspicuous layer in sections of old roots, as their walls remain thin and colorless. The cross partitions are reticulate-punctured.

In very young parts of the root the endodermis can be identified only by reference to the pericycle (fig. 2). Its cells begin to thicken at about the same point as do those of the hypodermis, where the latter begins to interfere with the absorption of water. The thickening takes place cell by cell, rather abruptly in the individual cells, but without any uniformity throughout the layer, so that in some sections a few will be found well thickened, all the others still thin; while a little farther back most of them will be found to be thick. Counting all the endodermal cells in a section, an undue proportion of those which thicken late is directly outside the xylem rays, where passage cells would be expected. However, cells in this position are not infrequently among the first to thicken, whereas scattered ones found elsewhere are often among the last. Considering the zone with reference to the hypodermis at which the thickening of the endodermis begins, it is evident that it is only as the water travels obliquely up the root to the stele, and not directly inward, that any of the cells remaining thin have occasion to serve in its passage. The appearance of the old endodermis is shown in the accompanying figure (fig. 1).

[2] *Bot. Gaz.* (1904), **37**, 241.

The outer part of the cortex, immediately underlying the epidermis to a depth of three to six layers, is composed of cells smaller than the deeper-lying ones. The walls of these, while they are in young and active parts of the roots, are very thin, with a notably dense protoplasm. Subsequently the walls thicken, those of the outermost cells first, until the lumen is almost obliterated; they acquire a stony hardness and dark color (figs. 3 and 4), thus forming a closed shell around the root, protecting it against animals or fungi and having a mechanical value already mentioned. The imperviousness of this shell to water is shown by its effect on the epidermis and on the formation of pneumathodes. The zone in which the hypodermis forms is that at which the root ceases to absorb water from the soil.

The larger the root, the farther from the tip is this likely to be. In very active ones the distance is as much as 5 centimeters; in those less active, but by no means inert, having a diameter of 7.5 millimeters, it is found to be 2 centimeters from the tip, while during drought it advances to a position well within the firmly adherent part of the cap.

Between the hypodermis and endodermis the cortex is composed of rather large cells, isodiametric or somewhat elongate longitudinally, with thin, colorless walls, watery contents, and numerous intercellular spaces (fig. 5). After the layers bounding it reach their final state, parts of the interlying cortex become unequally thick walled and lignified. At the basal end of old roots this intermediate cortex breaks, probably as a result of tension between the elastic stele and nonelastic shell, leaving the former loose inside of the latter.

The dermatogen is questionably distinguishable around the growing point, even in most favorable sections. The epidermis is a transitory tissue, dying when its connection with the inner part of the root is interrupted by the development of the hypodermis. Its most conspicuous feature is that the least diameter of its cells is the longitudinal (figs. 6–8). No root hairs are ever formed, but the superficial area is slightly increased by the breaking apart of the outer ends of the cells—a process which is most evident in longitudinal sections. In a soil where the supply of water is even moderately constant and ample the coconut root, with its short absorbing zone and absence of hairs, would be regarded as but a poor water gatherer, but when water is abundant, hairs are not needed; and in a dry time their sacrifice is spared to the coconut. A tree whose normal economy is planned on the absence of root hairs is comparatively well able to survive periods of abnormal difficulty in obtaining water.

Pneumathodes (figs. 9–14).—The development of the hypodermal shell so completely cuts off the interior of the root from all communication with the outside that it can not carry on the limited exchange of gases necessary for its respiration, and therefore it is obliged to develop special breathing organs, or "pneumathodes." These are specialized roots which quickly grow to a length of from 3 to 6 millimeters and then abruptly

stop. The cells of the cortex then enlarge; at first they keep their form, but afterwards they become spherical and finally put out processes each of which keeps in contact with a corresponding one from an adjacent cell. This enlargement of the cortex ruptures the epidermis and the growth of the inner layers separates the outer ones, so that the epidermis and outer layers flare back from both ends of the swollen zone; its surface is then mealy in appearance and white because of the contained air. As the pneumathode ages, the cap and all the outer tissues beyond the open zone slough off; the strongly lignified stele gives it stability and its sharp point will protect it against mechanical injury, if protection is needed. The cells of the open tissue necessarily promptly die, but their walls remain firm, their surfaces become granular, and in this condition they can not be wetted, so that the large amount of air contained between them can not be displaced. The cells next to the stele, and those at the base of the pneumathode—that is, those toward the parent root—enlarge moderately and become spherical, and thus form intercellular spaces of some size; their surfaces also become granular and their walls very thick, thus insuring the permanency of open aërial communication through the pneumathode to the tissue of the parent root, which has the most abundant system of intercellular spaces—that is, the cortical parenchyma.

Roots which have suffered metamorphosis to serve as pneumathodes have been encountered in many plants, and have been most thoroughly studied in this part of the world,[3] but in all previously known cases they are formed as a response to the wetness of the environment. In many plants which grow in wet places, either frequently or invariably, pneumathodes have become normal structures; in many others, whose roots only exceptionally find themselves where the supply of air is cut off by water, pneumathode-like structures form as abnormalities.[4] In plants whose habitat is such that pneumathodes have become a normal structure, the roots which serve this purpose have usually acquired a negative geotropism, adapting themselves to the direction in which the air is to be found. This is true of Phoenix, whose pneumathodes, as figured by Tischler,[5] are very similar to those of *Cocos*.

In distinction to all other known pneumathodes, those of *Cocos* are demanded by the structure of the plant without regard to what its environment may be. They form on roots in water, in firm ground, in loose sand, and in the air. In soil containing free air, where the roots normally grow and the formation of the pneumathodes is under the control of

[3] Karsten: Ueber die Mangrove-Vegetation im malayischen Archipel. *Bibliotheca botanica* (1891), Heft 22.

[4] The same is true of other parts of the plant as well. See Sorauer: "Ueber Intumescenzen." *Ber. bot. Gesell.* (1891), **17**, 456, and my note on Haberlandt's new organ on Conocephalus, *Bot. Gaz.* (1902), **33**, 300.

[5] Tischler, G.: Ueber das Vorkommen von Statolithen bei wenig oder gar nicht geotropischen Wurzeln. *Flora* (1905), **94**, 35.

natural selection, it is of course a matter of indifference whether they are above or below the parent roots; and no factor of the environment has the least influence in determining the place of their origin or the direction of their growth. They spring out at right angles, in all directions, and are straight. In water and in air they behave in exactly the same way. Exceptional length and negative geotropism would be appropriate reactions on the part of the pneumathodes emerging under water, but since the roots will not grow into water nor into soil without free air, their formation in this situation must be too abnormal and too rare a mischance for natural selection to have evolved any adaptation to it.

Absorption.—The same forces operate to draw water into the roots of plants which afterwards cause its movement to the leaves. There are—

(1) Suction exerted by the tissues surrounding the xylem ends in the leaves, and ultimately due to evaporation from the leaves under the influence of the sun's radiated energy.

(2) The osmotic activity of the cells in the roots through which the water passes. The former is the major factor, and its dominance is more extreme in the coconut than in most plants. This is clearly shown by two facts, the first one being that dead tips of roots for some time continue to absorb water without any measurable decrease in the rate as compared with that which was present while they were alive, and the second one is that if the tips of active, growing roots are cut off and immersed in water with not more than 5 millimeters of the cut end emerging into a saturated atmosphere, drops of water are not exuded from the cut surface; it merely remains damp. When roots are cut or broken in the ground, a gummy substance with a characteristic odor sometimes exudes, but there is neither bleeding of water nor of a dilute solution.

However, water entering the roots through the living epidermis and passing through living cells of the cortex to the stele must move under the immediate influence of the osmotic activity of these cells; a movement of the water under natural conditions is thus effected because it is constantly withdrawn from the inmost layers by suction. In this way the turgor of the roots is a factor in the acquisition of water, even in those which never bleed. The absence of bleeding only demonstrates that the living cells of the root will not pass a part of their osmotically active substance along with the water to the xylem; high turgor in the roots and abundant water in the soil will not necessarily result in root pressure.

The turgor in the pith, and in all except the fine outer cells of the cortex of the absorbing zone of the roots, equals 0.25 to 0.3 normal potassium nitrate solution. The walls are so thin that they wrinkle everywhere when plasmolysis is extreme (fig. 5). In the fine cells, which later become the hypodermis, plasmolysis is not visible in a less concentration than 0.5 normal; it is possible that the denseness of the protoplasm, together with the osmotic pressure caused by the cell sap, is responsible for this rather high figure. Plasmolysis is hard to detect in the epidermis. The turgor usually, but not always, seems to be a shade higher

than it is in the most of the cortex—about 0.3 normal. In the roots of most plants there is a slight but not appreciably interrupted increase in the turgor, from the epidermis inward; but this increase is no necessary condition for the ready movement of water, and in the *Cocos* we find in practice the lower turgor to be internal.

In the youngest cells of the embryonal tissue which can be plasmolysed the limit is 0.5 normal. In the cap the turgor is for the most part 0.25 normal; and in outside cells, as long as they are alive, it is no less. All these determinations were made on roots which were apparently healthy and active.

In all my experiments on absorption by the roots homeopathic vials were used, of such a size that when filled to the proper point with water the weight was 40–45 grams. In the cork of each was cut a hole fitting the individual root to be used. The latter was freed from the ground, with the least possible damage, to such an extent as to permit the necessary downward inclination of the tip. It was then washed, and all loose remains of the cap were carefully removed from the part which was to be within the bottle. To insure the absence of any open wounds the whole exposed part of the root, except that which was to be within the bottle, was smeared with vaseline. Water enough was used to immerse more than the absorbing region of the root, and the bottom of the bottle was kept low enough to prevent the water from touching the cork. The root, with its bottle, was laid in half of a split joint of bamboo, to which the appropriate slope was given, and the other half of the joint closed over it, thus insuring cleanliness. The hole in the ground was covered with abacá leaves to prevent unnatural warmth. All roots were left in this condition for one or more days before determinations of weight began.

After this time, when any initial disturbance in the rate of absorption was assumed to have passed, the hole and bamboo were opened, the bottle carefully removed, the root being touched by the bottle once to remove any free drops, and then a weighed bottle of water was substituted, the cork always remaining with the root. When all necessary care was taken to prevent wetting the cork, neither bottle needed to be open for more than five seconds, and the exposure of the root was even for a shorter time. The chief error in this method of experimentation is probably to be found in the variable amount of water adhering to the root, but experience shows that the results are reliable to a limit of 1 centigram.

The chief facts I endeavored to ascertain with regard to the absorption by the roots were the rate at which it normally takes place and the regular diurnal variation, if any, which may be found in this rate. I have also made some experiments on the absorption of solutions of potassium nitrate.

With regard to the usual rate of absorption, as has been seen to obtain for the growth, the first preliminary series of experiments demonstrated that roots which to the eye appeared to be similar behaved very differently. Nor was there correlation between vigorous growth and rapid absorption.

I made four sets of experiments, with essentially the same results; here it will suffice to give one of these.

This set was begun on January 11 and weighing commenced on January 13; but this beginning was made abortive by a rain which flooded the whole site. A new start was made on January 17. The weights given here are in centigrams, and are the average absorption for each day comprised in the interval ending at the date at the top of the column:

Root No.	Jan. 20.	Jan. 23.	Jan. 27.	Jan. 31.	Feb. 3.	Feb. 10.	Mar. 1.
I	6	6	6	7	7	3	7
II	15	6	15	19	19	14	12
III	19	8	[a]6	11	14	[b]22	28
IV	8	8	2	3	9	8	7
V	[a]16	18	28	35	43	43	(3)
VI	7	11	10	[b]3	3	3	.6
VII	[a]48	[c]47	52	53	40	[d]39	39
VIII	6	7	8	9	[d]5	7	8
IX	3	2	6	6	[c]5	7	-------
X	41	33	[c]39	39	49	36	17

[a] Pneumathodes appeared.
[b] Growth conspicuously rapid.
[c] Apparently dead or dying.
[d] Cap sloughed (absorption greater than figures show).

The root V was injured February 10, and was then cut with a sharp knife without exposing the surface to the air, and the cut surface was then immersed just as the uninjured tip had previously been; the total subsequent absorption was only 63 centigrams. I had already satisfied myself that practically no water can be absorbed by cut leaves, and the same disadvantage from the experimenter's standpoint is presented by the roots. It is of interest to note that while an open wound is very promptly plugged, dead tips maintain their full absorbing activity for a considerable length of time.

From these results I do not believe accurate conclusions can be drawn as to the total absorption by an entire tree. The very great diversity in the rapidity of absorption by the roots is but one of the reasons for this. From a considerable number of measurements on different roots I can say that, as a general average, the end of a main root, which, on anatomical grounds, appears to be in a condition to absorb water, has about one-sixth of the total surface possessed by all the root tips tributary to it. If absorption were proportional to the exposure of living epidermis, then the most rapid rate exhibited by any of these roots would indicate a total daily absorption by a large tree of only about 24 liters. But there is no such correlation between living epidermis and absorption, as is shown by the behavior of dead roots and by the two mentioned in the preceding table, the growth of which was temporarily most conspicuously rapid. The immediate result of the rapid growth was a long zone of young tissue, but in one of these cases the ensuing absorption was remarkably slow.

The tips of the fine ultimate branches do not individually absorb with sufficient rapidity to give me trustworthy differences in weight, and they are too far apart to permit the use of several at once without a disproportionate increase in the water to be weighed. In a single instance I was able to include three of them in one bottle of the usual size, and then the observed absorption per unit of area was about three times as great as I ever found it with the tips of the main roots. No far-reaching conclusions are to be based on one fortunate observation; but it does show, as we must also conclude from the experiments to be described on transpiration, that the total absorption can be much greater than measurements made even on many tips of main roots would indicate. In one experiment, the tip of a small main root 5.5 millimeters in diameter showed a maximum rate for the time covered by eight weighings of 2 centigrams per diem.

Because of the slight difference in weight to be determined, it was useless, in undertaking experiments to show the relative absorption during different parts of the day, to work with roots which had not already shown themselves to be among the most active. In two sets of experiments I have used such roots for this purpose. The result has always been that the greatest relative absorption was observed during the afternoon, and, so far as any conclusion could be drawn in such detail, during the latter part of the afternoon. This difference, at different hours, is usually less marked than it appears to be from the following table, which shows the results for one day with the four most active roots represented in the preceding table. The roots bear the same numbers. This experiment began at 6.15 a. m. February 1. The figures are centigrams of water absorbed during the preceding interval:

Root No.	Feb. 1.		Feb. 2, 6.15 a. m.
	12.15 p. m.	6.15 p. m.	
II	5	11	5
V	14	21	16
VII	10	19	10
X	12	22	17

From the fact that decidedly the most rapid absorption is during and closely following the hours of most rapid transpiration, it is a reasonable conclusion that the tree contains practically no store of water on which it can easily and safely draw. However, no conclusion is justified as to the total water actually contained in the path of the transpiration stream, and therefore none as to the rapidity with which the water moves. The water may rise slowly but the demand still be propagated rapidly.

My experiments on the absorption of potassium nitrate are open to the same criticism as pertains to all of my other absorption experiments,

namely, they had to be made on the tips of the main roots, which are not the places where the process is most active. In working with these solutions, trouble with red ants, which only exceptionally interfered with experiments with pure water, became serious; as a consequence I was finally obliged to seal all the tops of the bottle deeply with vaseline, thus completely cutting off the access of air to the water in the bottle; controls with pure water showed that during the time of these experiments very little if any interference with the absorption resulted. The investigations were made with the same roots which furnished the material for the preceding tables, and they immediately followed the conclusion of the period already reported. These results were scattered through too many days to make a tabulated report feasible. In each case the absorption of the solution is compared with that of water during the preceding period, which usually was of one day.

A solution of 0.1 normal reduced the rate of absorption for root VII from 40 centigrams (for the preceding twenty days) to 35 centigrams, which is within the limits of daily fluctuation. It was likewise questionable, in the case of main roots, whether there was any reduction by a 0.2 normal solution; for instance, with root II the rate actually increased from 14 centigrams to 15 centigrams. However, in the case of the three lateral roots, the rate fell from 51 centigrams to 16 centigrams, and after two days they were evidently unsound.

The results obtained with 0.5 normal solutions were various. With root III the decrease in absorption was only from 18 centigrams to 8 centigrams; tested again with water, the rate rose to only 10 centigrams; another application of the solution reduced it to 7 centigrams; and in water it again rose to 10 centigrams. With root I, the previous rate having been 7 centigrams, successive determinations were 1 centigram, 1 centigram, and 2 centigrams; in water the rate returned to 8 centigrams. With other roots the half-normal solution was found to be sufficient to reverse the movement. Thus root VI, which had been very regularly absorbing about 1 centigram, *lost* 2 centigrams, 3 centigrams, and 2 centigrams. Root VII lost 1 centigram at one time and the three fine roots lost at the same rate.

Immediately after losing at the rate of 1 centigram for four days, root VII was put into a normal solution, and it then gained 8 centigrams in one day. This result, which at first sight was surprising, is easily explained. Water moves through the root in the direction in which it is driven by the greatest pressure. Under ordinary circumstances this direction is inward because of the influence of the atmospheric pressure, the pressure within being less than that without. This may be expressed by stating that there is a "suction" from the inside. In using the more dilute solutions other agents must have acted together with the atmospheric pressure—agents which perhaps were put in operation by the solutions themselves; in this way the fact that the solution is absorbed will account for the result. With the half-normal solution the osmotic pressure was superior to the sum of the forces tending to make the water enter; as a result, it moved outward. Other roots may have absorbed this 0.5 normal

solution more readily, and so have been able to keep up a slow, inward flow, for in proportion as it is absorbed it exerts no pressure. But the normal solution was sufficiently concentrated to plasmolyse all the living cells, after which it was possible for the solution to travel from outside of the root into the xylem without being compelled to pass through any of these. When this condition results there is no semipermeable membrane in its way, and, concentrated as it is, it can exert no osmotic pressure. If the half-normal solution were to cause general plasmolysis then it also would enter freely and for the same reason.

The turgor of root VI was tested. This root had lost water to the half-normal solution. A few cells in its cortical parenchyma were found to plasmolyse in this solution, but the turgor of most of them was decidedly higher—about 0.7 normal. Some cells which did not plasmolyse even in such a solution did so in a normal one. There was no active epidermis, for the hypodermis had developed so as to be only 1.4 millimeters behind the growing point, well within the adherent part of the cap. The turgor of the cap was rather below 0.5 normal. In the meristem the limit was slightly higher, but the regulation had not kept pace with that in the cortex; and in the latter it was not what might have been expected from the observations of Stange [6] on the roots of various European plants.

My experiments on the absorption of potassium nitrate conspicuously show that the absorbing activity of the coconut roots is little interfered with by a moderate concentration of the surrounding solution (up to at least 0.2 normal). This obviously fits it for life in its typical habitat; for, while the water in the soil near the sea, and even in the beach itself, is not usually saline, because its mass movement is seaward, yet strand plants are subject to inundation during storms, which sometimes bring an amount of sea water about their roots which would be fatal if they were more sensitive.

THE COCONUT LEAF.

Gross morphology and growth.—Aside from the cotyledon, which is a very short sheath at one end with an enormous absorbing structure at the other, the first leaves of the coconut are mere sheaths, resembling the bases of later leaves, but entirely destitute of any lamina. These sheaths are usually 4 to 6 in number, each being longer and less scale like than its predecessor. In vigorous seedlings they sometimes appear at intervals of less than one week, but as a rule the succession is slower. Their most rapid measurable growth is immediately after they emerge from the nut. The transition from sheaths to leaves may be abrupt; or there may be one or two, the upper part of which, after splitting, bends outward, like the rachis of a leaf, but develops no blade.

The succeeding leaves, 2 to 6 in number, do not become pinnate, but develop a lamina, which splits down the median line, sometimes merely forming a notch, but usually extending more than half of the length of the

[6] Stange, B.; Beziehungen zwischen Substrat-concentration, Turgor, und Wachsthum bei einigen phanerogamen Pflanzen. *Bot. Zeit.* (1892), **50**, 253, etc.

blade. The most rapid growth of the later of these leaves occurs at a period which is a week or more after their emergence. They are plicate in vernation, but the folds are shallow and are almost or entirely smoothed out when the leaf is fully expanded. The result of this is an increase in the area of the leaf, without a corresponding growth of its margin; and this, in turn, causes it to become convex on the upper surface and to curve outward, whereby its exposure to light is materially increased, and the stomata-bearing nether surface is protected against wetting by rain. The first ones of these split leaves are apparently sessile, with blades about 20 centimeters long; the later ones are short stalked, and the length of the blades may exceed 70 centimeters.

The transition from split to pinnate leaves is a gradual one. At first only a few of the lowest folds separate, the appearance of the greater part of the lamina remaining like that of one of the merely split leaves immediately below it; in succeeding ones the pinnate lower part increases at the expense of the compact upper part until the latter ultimately disappears. The number of leaves sharing in this transition varies considerably, 6 being a common one. In length they may be from less than 1 meter to a size considerably larger. The earlier leaves are all short lived, and, as each succeeding one is larger than the preceding, their dimensions on a young tree are constantly increasing. In cultivation the nuts are germinated collectively and the seedlings set out in their permanent places during the split-leaf stage. The increase in diameter of the mass of the bases of the petioles is constant, and as the leaves have sheathing bases, as the tree grows, the latter rise into the air as a false stem, resembling that of the banana or abacá; this false stem reaches a height of about 150 centimeters before the real stem or trunk is visible. For several years after the appearance of the trunk, the leaves continue slowly to increase in number and in length. When the first nuts appear, at an age of from five to nine years, the tree is bearing at least twenty leaves. Even after this time there is usually some increase in their size; in vigorous old trees the number is 25 to 30 or even 35; each of these leaves is from 5 to 8 meters in length, with about 80 pairs of pinnæ, large and small.

The following table shows the rate of growth of the scales and split leaves of a number of seedlings. The measurements are from a mark on the lowest visible sheath, the husk not being dissected away; therefore there may have been some of the oldest sheaths invisible and not represented; and the growth being basal, the mark on the lowest visible sheath can record no growth. The entire elongating region is always within the protecting sheaths of the lower leaves, so that zones marked on any visible part of the leaf retain their exact intervals. Leaf No. I is the one which was marked, the others being successively younger. The numbers in parentheses represent total length; the others, the growth during the time

elapsing since the preceding measurement. Blanks indicate no growth. All measurements are in millimeters. "G" is the girth:

Leaf No.		Dec. 15.	Dec. 22.	Dec. 29.	Jan. 5.	Jan. 12.	Jan. 19.	Jan. 26.
I	1	(9.5)						
	2		(11)	10	5	3		
	3			(22)	20	17	10	
	4					(65)	28	
II	1	(11)						
	2			(7)	2.5	1	1	
	3		(12)	14	11	11	9	8
	4						(18)	8
III	1	(11)						
	2	(37)	10	4	2	2	2	1
	3		(66)	23	14	11	7	4
	4		(67)	48	44	46	46	51
	5							(180)
IV	1	(20)						
	2	(40)	3	2	1			
V	1	(29)						
	2	(56)	7	2	2		1	2
	3	(103)	38	23	20	13	8	3
	4	(67)	39	36	41	53	38	29
	5				(89)	52	43	54
	G	(28)	3	2	4	1	3	4
VI	1	(16)						
	2	(46)						
	3	(80)						
	4	(109)	16	18	14	5	2	2
	5	(120)	51	53	53	48	51	33
	6				(142)	49	56	65
	G	(28)	6	1	5	2.5	4.5	3
VII	1	(5)						
	2	(46)						
	3	(103.5)						
	4	(204)						
	5	(469)	7	1	1	3	3	1
	6	(586)	109	28	33	4	1	8
	7	(399)	71	81	73	85	91	91
	8						(352)	92
	G	(60)	5	2	1	2	5	4
VIII	1	(38)						
	2	(126)						
	3	(390)						
	4	(633)	25	6	11	3		
	5	(342)	69	64	21	18	46	36
	G	(57.5)	2.5	3			1	

Under fair conditions each leaf of a young tree grows decidedly more rapidly than the next older one, and in seedlings which are of the size of the ones mentioned above, several leaves grow rapidly at the same time. While the plants represented in this table were under observation the growth of their roots was prevented by frequent moving. This injury was reflected by a slower development of the shoot before the measurements ceased. Each leaf had less than the normal advantage over its

predecessor, and its period of rapid growth was abnormally short, so that in most cases only a single leaf was growing vigorously on each seedling.

Working as I did in the open and therefore largely depending on nature for modifications of the environment, it was very difficult to secure any reliable data on the influence of the individual factors of the environment on so slow a process as growth. Of the plants represented in the foregoing table, those with even numbers were watered twice daily during the first two weeks. As compared with the alternate ones, which were placed in an otherwise drier place and which received as much as 1 millimeter of rain but once in fourteen days, the growth of the watered plants was much slower, but the relative rapidity of development was not affected by reversing the positions during the succeeding fortnight; from which it appears that the difference was inherent in the individuality of the plants, and that it is a matter of practical indifference to seedlings of the ages of the ones which I was observing whether they be given much water or very little. Observation of a seed bed where more than 5,000 nuts were placed to germinate justifies this conclusion. Differences in the exposure of different parts of this bed were not reflected in the growth of the seedlings. Until the area of the leaves permits an appreciable transpiration, the nut must contain all the water the seedling normally demands for its growth. If the husk is entirely dry the roots do not emerge from it, but this may as well be due to the extreme toughness of the dry husk as to the abnormal loss of water from the roots and to any inability on their part to absorb water. After this time a removal of the roots or a prevention of their growth by frequent moving stunts the development of the seedlings, and no amount of water will altogether obviate this result, though, of course, the injury is fatal only when excessive dryness or some other cause prevents the development of new roots. Whether the injury to the growth of the shoot of well-watered plants is correlative [7] or because enough water can not be absorbed is uncertain, but in either case the leaving of the seedlings in the germinating bed after the nut's supply of water ceases to satisfy all demands, will result in injury when they are transplanted, even under the most favorable conditions.

The available moisture determines the rate of growth of the leaves of older plants to the practical exclusion of the influence of all other factors. My work on these older plants began after the influence of the dry season was seriously felt. Drought interferes first with the growth of the youngest individuals, the larger one suffering less, in proportion to the depth and extent of their root systems. The following table shows the growth of one plant (A) the development of which had practically been arrested, and of another (C) which up to the time of observation had comparatively been but little affected. In each case a leaf tip barely protruded

[7] Kny: Correlation in the Growth of Roots and Shoots. *Ann. of Bot.* (1894), **8**, 265. Townsend: The Correlation of Growth Under the Influence of Injuries, *Ibid.* (1897), **11**, 509.

from the mass of bases. A stout stake was driven into the ground until its top was exactly even with the tip of this leaf. All measurements given are from the top of this stake and are expressed in millimeters. Increments since the preceding measurements are indicated by boldface type. The heights of the stakes were, respectively, 500 and 1,320 millimeters. The experiments began on February 8:

Date.	Leaf A.		Leaf C.	
Feb. 10	1	----------	**40**	----------
Feb. 17	2.5	**1.5**	190	**150**
Feb. 22[a]	3	**.5**	306	**116**
Feb. 24	(16)	(13)	----------	----------
Mar. 1	88	**85**	404	**98**
Mar. 10	311	**223**	550	**146**
Mar. 17[b]	494	**183**	665	**115**
Mar. 23[c]	659	**165**	772	**107**
Mar. 30	784	**125**	885	**113**
Apr. 6[d]	895	**111**	1,004	**119**

[a] Plant watered.
[b] Leaf begins to expand.
[c] Watered last, March 20.
[d] Marked part of both leaves expanded.

The following contains a more detailed tabulation of the growth of these two leaves for a portion of the time included in the preceding one and shows the relative growth by day and by night. All measurements given are the increments during the preceding periods:

Date.	Hour.	Leaf A.		Leaf C.	
		Day.	Night.	Day.	Night.
Feb. 22	6 a. m.	---------	---------	---------	---------
	9 a. m.[a]	---------	---------	1	---------
	9 p. m.	---------	---------	0	---------
Feb. 23	6 a. m.	---------	---------	---------	5
	12 m.	---------	---------	0	---------
	6 p. m.	---------	---------	1.5	---------
Feb. 24	6 a. m.	---------	---------	---------	11.5
	6 p. m.	---------	---------	1.5	---------
Feb. 25	6 a. m.	---------	---------	---------	15.5
Mar. 10	6 a. m.	---------	---------	---------	---------
	6 p. m.	3	---------	0	---------
Mar. 11	6 a. m.	---------	19	---------	15
	6 p. m.	3	---------	0	---------
Mar. 12	6 a. m.	---------	21	---------	18
	9 p. m.	8	---------	3	---------
Mar. 13	6 a. m.	---------	15	---------	13

[a] This interval follows the first watering of leaf A too promptly for the growth to be at all normal.

A few measurements at other times agreed entirely with those given above in demonstrating that the measurable growth very largely took place at night, the diurnal growth of the plants which were seriously

suffering from drought falling to nil. Indeed, a slight but unmistakable shortening occurred on certain of the days of observation. The reason for this strikingly unequal distribution of the growth is that the active transpiration during the day creates an internal scarcity of water and reduces the content of that liquid in the plant to such an extent that any considerable enlargement is impossible. A similar, but much less pronounced, daily periodicality of growth is reported for the bamboo,[9] [10] correlated with the relative humidity. Every factor which contributes to the more active transpiration during the day is also in part responsible for the cessation of growth.[10]

It is a very common practice in Mindanao to plant coconuts and abacá together, in the expectation that the abacá will support the commercial undertaking until the coconuts mature. This may be expedient, from a business standpoint, where the cost of clearing is the chief item in the establishment of a plantation; and after the first two or three years the coconuts suffer less than the abacá in this competition; but the maturing of the former is delayed by probably two years, and the trees are never as robust as those which were better illuminated from the start. The ultimate diameter of the trunk of a palm is determined in its youth.[12]

The heliotropism of the coconut is illustrated by the well-known disposition which trees along the beach have to bend toward the water (fantastically ascribed to the tree's love of the sea) and by the tendency of those around the outer edges of a grove to lean outward in every direction. This heliotropism is the more interesting because the actual growing region, where the curving takes place, is deeply seated below the visible tip and covered by the bases of many leaves.

The negative geotropism of the trunk causes a prostrate tree to turn upward with a curve the radius of which often does not exceed twice the ultimate diameter of the trunk. This abrupt curvature is rendered possible only by the harmonious reaction of many growing leaf bases, those beneath developing more and those above less rapidly than the ones in the middle. Each leaf base executes its own appropriate curve. These

[9] Lock: *Annals Bot. Gard. Peradeniya* (1904), **2**, 211. Not seen.

[10] Kraus (Das Längenwachsthum der Bambusrohre, *Ann. Jard. Bot. Buitenz.*, 1895, **12**, 196), working at Buitenzorg, with almost daily rain, found the diurnal retardation of the growth of bamboo slight, compared with that reported here for *Cocos*.

[11] At least the larger proportion of the experiments which are supposed to show that light exerts a direct retarding influence on the growth of stems and leaves are questionable because they do not exclude the possibility of the direct influence of the illumination on the transpiration and a consequent indirect retardation of growth. While the immediate effect of light is to retard growth, adequate illumination is of course eventually indispensable for the healty development of the plant.

[12] The nuts in a seed bed are usually placed horizontally because the trunks grown from such seeds are supposed to be stouter. Drude, in *Natürlichen Pflanzenfamilien*, II, **3**, 3, states that some palms, such as *Sabal* and *Ceroxylon*, normally develop stouter trunks if their earliest growth is horizontal.

reacting bases are organically connected only by means of tissue which must completely have ceased to grow (it is not available for measurement), and the harmony of the entire reaction is no evidence of any communication between the units concerned in it.[13]

Anatomy of the leaf.—In describing the anatomy of the coconut leaf nothing need be said about the fibro-vascular tissue except that the finest longitudinal veinlets are hardly more than 0.1 millimeter apart, so that water in order to reach any cell of the parenchyma only needs to pass an exceedingly short distance by osmosis. The structure of the individual veins and veinlets offers no peculiarities.

The most striking structure in the leaf is what may be called the "hinge." Running ventrally for its entire length along each side of the midrib of the pinna is a narrow strip, sharply differentiated from any neighboring living tissue by its colorless contents. A crease along the middle of each of these strips makes the leaf thinner at this point than anywhere else, the colorless hinge tissue occupying more than half the thickness of the leaf but not entirely crowding out the green mesophyll. The epidermis of the hinge, as seen in transverse section, is remarkable for its exceedingly convex outer walls. The two accompanying figures (15 and 16) make this structure clear.

Because of the convexity of the outer walls of the individual cells, the wall of the epidermis, in this situation, as a whole is very much wrinkled; so that a bending or even a stretching can obviously be accomplished by a very slight and easy bending of walls at right angles, without giving rise to the uncompensated stretching of any one unit. Other parts of the leaf have the thick outer walls practically plane, and as any bending would involve the extension or direct compression of the whole of one of them these parts are practically rigid. Therefore, the crease mentioned above facilitates movement not only because it makes the leaf thinner at this point but also because it increases the convolution of the walls and reduces their resistance.

The active tissue concerned in the movements of the hinge is the colorless mesophyll. Its cells are large, and they have thin walls which are easily bent or even stretched. It is without intercellular space, so that the slightest alteration in the volume of the individual cells changes that of the entire tissue. The volume of the cells must obviously vary with their water content. When the leaf is well supplied with water the cells of the hinge are distended to their full capacity and it is open, thus holding the two sides of the pinna as far apart as possible. When the supply of water is insufficient the reverse takes place. By this means the exposure of the pinna to the rays from the sun or sky is lessened and a "dead air" space, though usually a very imperfect one, is formed under it. In both of these ways the further loss of water is checked.

When the pinna is losing water faster than it is being furnished from

[13] Cf. my paper, "The Geotropism of Split Stems," *Bot. Gaz.* (1900), **29**, 189.

below, the hinge responds before the cells of the green mesophyll begin to suffer. The explanation is as follows: All the cells hold their water through the osmotic activity of their contents; the turgor of the chlorophyll-bearing cells is such that plasmolysis begins in about 0.5 normal potassium nitrate, while the cells of the hinge begin to plasmolyse in less than 0.3 normal, as a consequence the latter will lose the greater amount of water in the shorter time, thus causing the hinge to close.

The actual behavior of the hinge is sufficiently illustrated by the following table, which gives the distance, in millimeters, between the edges of the two pinnæ, each measured 20 centimeters below the tip, at intervals, for two days:

Leaf.	Dec. 7.						
	7 a. m.	8 a. m.	9 a. m.	10 a. m.	11 a. m.	12 m.	1 p. m.
A	20.3	20.3	17.5	15	13	12.5	12.5
B	25	25	21	20	18	17	16.5

Leaf.	Dec. 7.			Dec. 8.		
	2 p. m.	3.30 p. m.	5.10 p. m.	6.30 a. m.	7.30 a. m.	8.30 a. m.
A	13	13	17	20.3	20.3	20
B	16	17.5	21.5	25	25	23

Leaf.	Dec. 8.							Dec. 9, 6.30 a. m.
	9.30 a. m.	10.30 a. m.	12 m.	1 p. m.	2 p. m.	4 p. m.	5 p. m.	
A	16.5	13.5	12	13	12.5	13.5	16.5	20.5
B	21	18.5	16	16.5	15	17	21	25

As the accompanying records show,[14] the months between November and April were exceedingly dry at San Ramon. The influence of this climatic condition on the behavior of the hinge is shown by the following measurements, in millimeters, made on the same leaves at the same points one month later than the date of the preceding table:

Leaf.	Jan. 11.		Jan. 12, 7 a. m.	Feb. 8, 7 a. m.
	6.30 a. m.	7.30 a. m.		
A	18	18	18	17
B	23.5	23.5	23	21

The surface of leaf B was moist on the morning of January 11, and this fact demonstrated that its failure to open as widely as it did a month

[14] See hygrometric readings appended.

before had become chronic. This was due to the prolonged drought and not to the age of the leaf, for in seasons of fair precipitation the pinnæ lose none of their original power of expansion, at least until they are much older than the ones measured in these experiments.

Aside from the hinge, the mesophyll is differentiated into the green assimilating, and what, in deference to custom, I will call a water-storing tissue. The latter is composed of two layers of cells, immediately beneath the upper epidermis. The upper of these layers has the cells elongated at right angles to the length of the pinnæ, as is shown by figs. 17 and 18, while those of the inner layers are considerably deeper and larger. Both are almost perfectly transparent and their contents consists almost entirely of water. They form no inconsiderable part of the volume of the leaf. Their walls are not sufficiently thin either to be collapsible or to stretch very easily, so that only an insignificant part of the water which they contain can ever be available to replace any loss on the part of other cells. They are primarily rather to be regarded as a screen, the function of which is to mitigate the injurious effects of too extreme insolation on the underlying green cells. The same is true of the thick-walled, so-called water-storing tissue of many other plants.

The green mesophyll is but feebly differentiated. There usually are two layers which may properly be termed palisade cells, and about four more, the cells of which are irregularly placed; but the leaf throughout is too compact for any tissue appropriately to be designated as spongy. The turgor of the assimilating tissue is equal to about 0.5 normal potassium nitrate.

The cells of the epidermal tissue are approximately isodiametric in surface view, their least diameter being the depth. They are devoid of chlorophyll, and hyaline. Their turgor is about that of the hinge cells, but their heavier walls prevent any considerable variation in their water content. The outer wall of the upper epidermis is 6 to 7 μ thick; that of the nether, 5 μ. The surfaces are glabrescent.

The stomata of the coconut leaf are confined entirely to the nether surface, where they number about 145 per square millimeter. They average in size about 30 by 33 μ with an area for the pores and for both guard cells of 740 μ square.

As the accompanying drawing of the transverse section (fig. 19) shows, the stomatal apparatus is practically superficial, the back of the guard cell being sunk just enough to make room for a hinge in the wall outside it and to permit it to move without interference from the thick, outer wall of the epidermis. The mechanism is exactly that of Schwendener's type of *Amaryllis*.[15] [16] The back wall of the guard cell is so thin that it collapses and wrinkles in plasmolysis. The ventral half of each, namely, the one next to the pore, is strengthened by the powerful ridges of

[15] Schwendener: Ueber Bau und Mechanik der Spaltöffnungen, *Monatsber. Akad. d. Wiss.*, Berlin, 1881, 833.

[16] Copeland: The Mechanism of Stomata, *Ann. of Bot.* (1902), **16**, 339.

entrance and exit and by the neighboring, comparatively heavy parts of the wall. Anticlinal walls never strike the guard cells midway. A more detailed explanation of the mechanism of these stomata would be superfluous here. However, there are some interesting features about their turgor and their behavior under changes of illumination and with the gradual withdrawal of their water which render it worth while to introduce some measurements. The agent employed by me to withdraw the water was potassium nitrate. The solutions were 0.3 normal, 0.5 normal, and normal. Measurements are in microns:

	In pure water.	0.3 normal.	0.5 normal.	1 normal.
Stoma:				
Length	34	35	35	34
Width	31	30	28	26
Pore, width	5	3	1.5	0
Ridge of exit	9	7.5	7	6.5

The normal solution plasmolysed the guard cells and caused the contents of other epidermal cells to collapse until they occupied hardly half the previously visible area. Remaining ten minutes in this solution killed many of the former, and others opened the pore only after the solution was replaced by water and the slide exposed to the direct sunlight. The two stomata described below half opened in water and completely in the sunlight. Measurements are in microns:

Leaf.		Direct sun.	Obscure light.		Microscope stage.	
			15 minutes.	75 minutes.	10 minutes.	15 minutes.
A	*Width:*					
	Stoma	32	31	29	30.5	31
	Pore	5	4	2	3	4
B	*Width:*					
	Stoma	30.5	30	30	30.5	31
	Pore	5	3	0.5	2	3

It appears from these measurements that seventy-five minutes in quite diffuse light affects the degree of opening of the pore about as much as does immersion in 0.5 normal potassium nitrate solution. The recovery of turgescence with better illumination occurs with amazing promptness when one considers the great change in turgor which precedes and causes it. In this experiment, as is always necessary when stomata are under prolonged microscopic study undertaken with sufficient care to permit of accurate measurements, they are immersed in water. When they are in the natural condition on the living plant they respond much more quickly and thoroughly to the withdrawal of the light, as is shown by experiments to be reported below, in which the rapidity of transpiration is determined by the cobalt test.

While all recent writers on the subject have assumed that changes in turgor are responsible for the changes in turgescence with variations in the illumination, it has never, so far as I am aware, been demonstrated that the turgor really does vary.[17] I myself have tried to measure such a change with divers plants, but without success. However, with the coconut it is easy to determine that the turgor is much higher in light than in darkness, though the actual differences are rather inconstant. The turgor of a single pair of guard cells can be demonstrated to change during a prolonged experiment; but as this involves plasmolysing the pair at least twice, and, as a rule, subjecting it to several strong plasmolysing solutions, each of which must be given time to act, the cells are likely to suffer changes from this treatment. The evidence taken from the observation of many different stomata, in their natural condition, at different times of day, is more valuable.

The turgor on sunny afternoons is usually about equal to normal potassium nitrate. Sometimes it exceeds even this high figure. Thus at 3.30 p. m. November 25 these measurements, in microns, were made:

	0.5 normal.	0.7 normal.	1 normal.
Pore, width	2.5	1.5	Closed.

While the particular stoma under observation was not measurably open, about one in five on the section was open to the extent of at least 1 μ, the plasmolysis of any guard cells being very doubtful; but when the normal potassium nitrate was replaced by glycerin, plasmolysis was evident everywhere, and all stomata were closed. If they were examined early in the morning the guard cells were usually found to have their turgor equal to somewhat less than 0.7 normal potassium nitrate but rarely below 0.6 normal. In direct sunlight the increase is an immediate one.

The action of prolonged darkness is very different from that of the mere nocturnal lack of light. A leaflet was kept in darkness, inside a wooden cylinder, for ten weeks, at the end of which time its turgor, as compared with that of a neighboring pinna under ordinary conditions, was:

Name.	From darkness.	From normal leaflet (in morning).
Epidermis	0.5	0.25–0.3
Guard cells	0.9–1.0	.6 – .7
Parenchyma	.7	.7 – .6

[17] The term "turgor" is used to express the osmotic pressures of the *internal* fluid of a cell. On the other hand, the expression "turgescenee" applies to the strain resulting from the interaction of the force of the osmotic pressure (the diffusion tension of the solute) on the one hand and that of the resilience of the cellulose membrane on the other. Copeland, *Ann. of Bot.* (1902), 16, 330.

In my paper, "Ueber den Einfluss von Licht und Temperatur auf den Turgor," [18] I showed that in leaves growing or grown in darkness the turgor is higher than in normal ones; but the pinna of the coconut which I had under observation did not, at least in area, grow during the experiment, therefore the explanation in this case must be a different one.

TRANSPIRATION.

Three general methods have been used in research on the transpiration of plants: First, measuring the water absorbed by the subject of the experiment; second, determining the loss in weight of the subject and its container; third, ascertaining the amount of transpired water after it leaves the plant. I have used all of these in my work on the coconut.

The first method is of the least value because it does not directly measure the transpiration, and because the amount absorbed and that given off in a given time are not necessarily equal. I employed it in some preliminary experiments only, when my equipment did not permit the use of either of the others. As the pinnæ which served as subjects always lost weight almost from the beginning of the experiments, absorption being less rapid than transpiration, the method is inapplicable when any measure of accuracy is desired. It will, of course, be understood that all ordinary means of keeping the absorption normal were employed.

In all experiments on the transpiration of this plant in which the subject is to be weighed the use of single pinnæ is practically compulsory, for even young seedlings are so heavy that the loss of water from the limited leaf area in such time intervals as one hour would escape notice. Entire leaves have the same disadvantages as do pinnæ, and besides they are most unwieldy. When it can be used at all, the determination of the loss of weight of subject and container is the most reliable method of ascertaining the transpiratory activity of any plant, and when, as in this case, the use of whole plants is impracticable, it is usually feasible, with proper care and precaution, to be sure that isolated parts of them behave, at least for some time, as they would in their natural positions. I have used this method in the larger part of my work, but, in contrast to experience with other plants, have found it quite impossible to make single, isolated pinnæ of the *Cocos* maintain the normal rate of transpiration for more than a very short time. Leaves cut under water, with the cut surface at all times protected from exposure to the air, approximated normal transpiration but little if at all more closely than those treated without this care. This has repeatedly been my experience. One rather extreme illustration will suffice to demonstrate it: The cut surface was never exposed to the air. The first weighing was immediately after cut-

[18] *Dissertation*, Halle, a. S., 1896.

ting. The leaf was exposed to direct sunshine during the greater part of the time:

Interval.	Loss of weight.	Loss per minute.
Minutes.	*Gram.*	*Gram.*
6	0.15	0.025
13	.17	.013
50	.26	.005
310	.70	.002

The average loss per minute during the last interval was only 8 per cent of that during the first. Transpiration does not usually cease so promptly, and the relative loss is less, the longer the first period is made. It is a general rule, in experiments of this kind, to permit the subject to stand for a time after cutting, and thus to become accustomed to its new conditions before observations really begin. If this is done with *Cocos* the rapid initial transpiration can not be observed, and thus the abnormality of the results obtained must escape suspicion. Many of my tables, which seemed satisfactory when made, are valueless on this account. When the transpiration of a leaf varies during a single half day by 92 per cent of its maximum activity, independently of any change in the environment, it is obvious that any modification of the latter must have results which are comparatively too insignificant to be studied with any confidence. Therefore, I was forced to seek a means of preventing the usual reaction to the cutting of the pinnæ.

The water in which cut pinnæ stand ceases to be clear, becoming a pale, often opalescent, brown. This is sometimes evident within half a day after cutting, but usually it is not seen until a day or more has elapsed.[19]

Suspecting that an exudation from the cut surface (though none was visible) might be preventing the absorption of water, I tried renewing the cut. It was doubtful if the transpiration was accelerated; certainly such acceleration was not enough to be applicable in drawing any conclusions.

It was shown by Janse [20] that, while boiling a part of the path of the transpiration stream ultimately results in interference with the movement of water, this result is not immediate, and is due to changes in the part remaining alive, not in that killed. It occurred to me that boiling the bases of the pinnæ might prevent the checking of their absorption for at least a few days. As a matter of fact, the cessation was less immediate and less complete in pinnæ so treated than in others, but it was still so great that the results obtained by this method alone are far from satisfactory. They are shown in the next table.

[19] This is a conspicuous exception to Sachs's statement that nothing escapes from such cut surfaces into water.

[20] Janse, J. M.: Die Mitwirkung der Markstrahlen bei der Wasserbewegung im Holz, *Jahrb. wiss. Bot.* (1887), **8**, 1.

The fact that neither renewing the cut nor killing the lower ends of the pinnæ prevented the practical cessation of the transpiration would suggest that this cessation is due to some reaction on the part of the stomata, but this can hardly be true, for, as already noted, the cut pinnæ lose weight during the experiments. The only explanation I can suggest for the persistent refusal of the cut pinnæ to absorb water at least as readily as they normally secure it from the rachis of the leaf is that a pressure of less than one atmosphere within the tracheæ is a condition for the ready movement of water through them, and that offering water to the pinnæ at a higher pressure than the usual one, instead of making them absorb more, is in itself the cause of their absorbing less. I am not ready to support this suggestion here, and know that it is contrary to the generally accepted opinion that water travels through wood with equal readiness regardless of whether the motive force is applied as a pressure (above one atmosphere) or as a suction (less than one atmosphere). It seems to me that this may be true in some cases and not in others, depending, for one thing, on the amount of air in the conducting elements.

Determining the water given off by leaves by absorbing and weighing it is a method which has long been in use. A decade ago, in a paper not accessible to me at the time I carried out this work, Stahl introduced the use of anhydrous chloride of cobalt, the rapidity of transpiration being estimated by its change in color from blue to pink as the salt absorbs water, because cobalt salts are blue when anhydrous, red when hydrated. As standards I used pieces of absorbent paper saturated with cobalt-chloride solution, one set not quite as blue as it would be if entirely anhydrous, the other not as red as if entirely hydrated; these sets were separately sealed in glass vials. While changing from the color of one of these to that of the other, a piece having an area of 100 square centimeters absorbed 0.46 gram of water. By the use of this cobalt paper the transpiration of pinnæ in their natural positions on the tree could be tested, the evil effects of cutting being entirely obviated. However, the method has compensating disadvantages.

The cobalt paper must be directly applied to the transpiring surface, and it must be protected against the possibility of absorbing water from the atmosphere. This is accomplished by holding it in place with glass (microscope slides serve the purpose well), the latter in turn being held by clamps. This method is likely to make the transpiration abnormal by interfering with the wind, by cutting off some of the illumination, and by placing a portion of the leaf, at least for a part of the time, in an abnormally dry atmosphere.

Transpiration is exceedingly sensitive to changes in the illumination, so much so that if a slide which is locally corroded be used over either surface, the paper under the etched spot will be noticeably slower to turn red; therefore clear and perfectly clean glass must be used. However,

there is no avoiding interference on the part of the cobalt paper itself; but nearly all of the light to which the plant has access comes from above, and the disturbing effect of cutting off that from below is correspondingly moderate.

The wind affects the transpiration in two ways—by constantly changing the air immediately outside the stomata and by agitating the leaves and thus causing a circulation within the intercellular spaces and an egress and ingress through the stomata. The disturbance of the first of these effects is inoperative in this case because of the drying action of the cobalt paper; and as the pinna as a whole remains fairly movable, only the small part between the slides being rigid, and the intercellular spaces are continuous, the interference with the circulation is at most but partial. The disturbance of the transpiration by cutting off the wind is therefore not a serious matter.

That the cobalt-chloride test of transpiration places the leaf in an abnormally dry atmosphere is a great and unavoidable objection. Even if the plant did not react to this condition other than as a surface of water would, namely, by more rapid evaporation, this error would be very difficult to control; for while the blue paper must constantly surround itself with very dry air, this medium becomes damper as the paper turns red.[21] In practice, the matter is far from being as simple as if we were studying evaporation from a water surface only. When the cobalt paper is applied to a surface with open stomata it suddenly makes an increased demand on the water vapor in the intercellular spaces which are in immediate contact with the open pores, and most particularly on the water in the guard cells themselves. An abnormally active escape results, this in turn causes the stomata to close, checking the loss, and this process presently brings the transpiration below the normal. Thus, the decreased illumination and abnormal dryness work together in reducing the transpiration, and their combined effect is to cause the paper to change color, at first more rapidly than the normal transpiration would make it do so, but afterwards much more slowly.

That the rapidity of reddening of the cobalt paper comes far from indicating the actual rapidity with which the plant loses water is clearly shown in the last preceding table, in which the time intervals are those required for the reddening to take place. As the first column shows, the initial reddening took place in one-fiftieth of the time consumed in the last interval. The second column shows the relation of the reddening to the actual, though abnormal, transpiration. The area of this pinna was 75.4 square centimeters. Of this, 19 square centimeters was under the slide, leaving 56.4 square centimeters free; 56.4 centimeters of cobalt paper would absorb 0.26 gram of water in changing color. Evidently

[21] Very soon after paper in contact with actively transpiring leaves is really red, water begins to precipitate on the glass.

the cobalt paper withdrew water from the leaf during the first two periods more rapidly than it transpired from the free surface but much less rapidly during the last period. The change from an acceleration to a retardation occurred in about half an hour; it often appears more quickly. The measurement of transpiration by weighing cut pinnæ and their container was deemed unavailable when this experiment showed that the rate fell during a few hours to 8 per cent of the initial. As determined by the cobalt test, the rate fell during the same experiment to less than 2 per cent. This exhausts the really distinct methods of making continuous direct determinations of the transpiration of a single subject.

Neither of these usually reliable methods being alone available in working on the coconut, I next had recourse to combinations, attempting to check a continuous experiment with one method by applying frequent corrections obtained from observations by the other; thus at the same time having the advantage of accuracy in the weighing method, and that of working with uninjured pinnæ on the tree by the cobalt test. I first tried to reach these ends by determining at intervals of several days the loss of weight of pinnæ placed in bottles of water, and at the same time comparing the rate at which cobalt paper was turned red by these cut pinnæ with that at which it was altered when it was applied to pinnæ *in situ* on the tree. My most satisfactory experiments of this kind furnished material for the following table:

The pinnæ A, B, and C were cut on the afternoon of January 17 and the cut ends killed by insertion in nearly boiling water. The leaf D was freshly cut at 2.30 p. m. January 18, and its ends not killed. All weights are in grams. The loss was determined regularly at one-hour intervals during the day. The bottles were hung in the tree, putting the pinnæ as nearly as was possible in natural conditions. The bottles themselves were shaded to prevent heating.

Date.	Hour.	A.	B.	C.	D.	Behavior of cobalt paper.[a]
Jan. 17	5.30 p. m.	--------	--------	--------	--------	
Jan. 18	6.30 a. m.	--------	0.12	--------	--------	
	7.30 a. m.	0.03	.02	0.02	--------	Red in 8 minutes; leaves were damp.
	8.30 a. m.	.14	.09	.09	--------	C and T change equally; not completed in 60 minutes.
	[b]9.30 a. m.	.10	.08	.09	--------	A and T the same.
	10.30 a. m.	.23	.13	.09	--------	B red in 40 minutes; T in 26 minutes.
	11.30 a. m.	.72	.42	.27	--------	One-third faster on T than on A.
	12.30 p. m.	.61	.40	.40		
	1.30 p. m.	.71	.63	.50	--------	A red in 55 minutes; T in 13 minutes.
	2.30 p. m.	.43	.74	.51	--------	A red in 55 minutes; T in 20 minutes.
	3.30 p. m.	.53	.50	.35	0.51	D red in 45 minutes; T in 13 minutes.
	4.30 p. m.	.39	.86	1.02	1.17	D red in 17 minutes; T in 13 minutes.
	5.30 p. m.	.14	.16	.12	.41	D red in 40 minutes; T in 18 minutes.
Jan. 19	6.30 a. m.	.10	.05	.09	.10	(These are totals for 13 hours darkness).

[a]T=Tree. [b]Sun strikes A at 10.20, B at 10.25, C about 10.40.

During the following day the transpiration was much slower and too abnormal to be worth reporting in detail. The totals for the twenty-four hours ending January 19 and January 20 were:

Ending—	A.	B.	C.	D.
Jan. 19	4.13	4.10	3.55	--------
Jan. 20	1.58	1.71	1.33	2.02

If now the transpiration of a pinna *in situ* be computed from the loss of weight by pinnæ in water, and the relative rapidity with which these and the former turn cobalt paper red, the following result is obtained:

Hour.	Grams.	Remarks.
7.30 a.m	0.03	Observed for A.
8.30 a.m	.14	Do.
9.30 a.m	.10	Do.
10.30 a.m	.23	Do.
11.30 a.m	.96	4/3 by 0.72.
12.30 p.m	.81	4/3 by 0.61.
1.30 p.m	3.02	4.25 by 0.71.
2.30 p.m	1.19	2.75 by 0.43.
3.30 p.m	1.78	3.5 by 0.51.
4.30 p.m	1.53	17/13 by 1.17
5.30 p.m	.91	2 2/9 by 0.41
Night	.10	Observed for A.
Total	10.30	For one pinna and one day.[a]

[a] The free area of leaves furnishing this figure averaged about 120 square centimeters, the rate therefore equaling 8.57 grams for 1 square decimeter. Haberlandt (Anatomisch-physiologische Untersuchungen über das tropische Laubblatt, *Sitzber. Wiener Akad.* (1892) **101**, I; 804, 807) found a rate for *Cocos* at Buitenzorg of 0.89 gram per diem per square decimeter of surface.

Allowing 150 pinnæ to the leaf and 25 leaves to the tree, this indicates a total daily transpiration for the tree of 38,551 grams. My estimates made in this way have ranged between 28 and 45 liters. These calculations are based on determinations made on sunny days, and some of them are doubtless higher than the average transpiration of the tree for all days. On the other hand, it is to be observed that no allowance is made for the fact that not all parts of the pinnæ under experiment were free to transpire.

Another way of combining the cobalt test with the weighing method is to use fresh leaves at frequent intervals. This combination offers the advantage that the transpiration of the subjects weighed is never very much below the normal, but the disadvantage that it is difficult, with such a frequent change of subjects, to apply a control based on the continuous use of the same pinna. In practice, if the cobalt paper is always applied to a fresh part of the pinna, it will turn red once or twice after the pinna is cut, at practically the same rate as before. Under ideal conditions this method will furnish really accurate results, but the test of a method is

its usefulness under unfavorable circumstances, and under them the lack of continuity becomes too great an objection; in addition, the observations demanded at short intervals on several pinnæ at once require a dangerous haste in manipulation. This method is serviceable where immediate results will answer, as, for example, in testing the effect of shading. Estimates of the total daily transpiration by this method, based on determinations made in the sun, run higher than those just given—sometimes as high as 75 liters per diem.

After this necessarily prolonged discussion of method, a brief consideration of the relative transpiration from the upper and nether surfaces of the leaves, the influence of their age on their transpiration, and the effect exerted from without by the illumination and the wind will be possible.

Almost the entire transpiration of the coconut is through the stomata of the nether surface of the leaf. In experimenting on the transpiration from the upper surface, and at no other time, have I found it necessary to seal the edges of the glass slides to prevent interference by the moisture of the atmosphere; of course, it was also necessary to guard against the passage of moisture from the nether surface to the upper. These precautions being taken, it requires at least six hours of continuous sunshine to enable the cobalt paper to change color. If the leaf is placed in the shade or in the dark, the hydration is somewhat slower. On January 21, a day when there were occasional clouds, the average time of reddening, when the paper was placed against the lower surface, was eleven minutes, but against the upper, seven hours; this interval, from 9 a. m. to 4 p. m., was required for the change; and paper blue at 11.25 was still of the same color at 5.30, but red at 8.

Experiments were made on the transpiration of leaves which were just full grown, those about six months older, and those a year beyond maturity. Two series of determinations were undertaken with the individuals of each age. These varied in detail, as is true with all of this work, but the relation was constant—the leaves six months beyond maturity transpired rather less than those which had just grown, while those a year old were decidedly the most active of all. For example, the total transpiration for seven hours, from 9.20 a. m. to 4.20 p. m., February 14, was—

	Grams.
Mature leaf	2.70
Six months older	1.68
One year older	3.37

The result for the leaf of mean age is too small; this is due to its being the first to become greatly abnormal. The totals for 4½ hours, from 1.50 to 5.20 p. m., February 15, were—

	Grams.
Mature leaf	0.78
Six months older	.75
One year older	1.50

When I first observed this phenomenon I was surprised that the oldest leaves showed the most active transpiration, but a few weeks later a paper by Bergen [22] was received showing that the coconut is not peculiar in this respect. The figures given above are not corrected for area; if this were done it would still further emphasize the difference, because in both cases the oldest leaves had the least exposed area. The relative activity of cut pinnæ and those *in situ* was at first exactly the same in all cases and so demanded no correction, but the oldest leaves were always the last to show an extreme depression. The transpiration from the upper surface was slightly more active in the latter, but it was not enough so to account for any great proportion of the extra quantity. A considerable part of the total area of the oldest leaves was occupied by small, scattered brown spots, and the leaf was dead two months after these observations. The tree was a young one.

Thirty or more determinations of the transpiration during the night have all shown concordant results, the rate being about 1 per cent or even less of the greatest during the day; the total transpiration for an entire night was about one-tenth of that during one hour of sunlight at midday. Three factors are responsible for this great nocturnal depression—the darkness, the lower temperature, and the higher relative humidity. The complete experimental analysis of these three factors was practically impossible, but the cobalt test, being independent of the moisture of the environment, is capable of showing the inflence of the illumination independently of the relative humidity.

By this test it has repeatedly been proven that a very slight shade will to a certain extent almost immediately depress the transpiration. Of course, actual darkness has a very much greater effect. In using the cobalt test I held the glass slides to the leaf with cork clamps, and therefore the spot immediately between these was in approximate darkness. When, in the first test, the paper reddened in about four minutes, the change was not appreciably hindered by the cork; but if this first test required more time, and always during subsequent tests, the darkened part of the paper was very evidently slower in turning. Beginning at 9.18 a. m. January 21 the intervals required for reddening were ten minutes and nine minutes; then, with a light haze over the sun, fifteen minutes; all these for the illuminated part of the paper. After the last determination, the paper was left until the part under the cork was reddened; in about forty minutes water was precipitating on the glass over the lighted leaf, but the darkened paper was still bluish, only becoming as red as the standard after ninety-five minutes—that is, it took more than six times as long to change as it did when a mere haze weakened the light.

[22] Bergen, J. Y.: Relative Transpiration of Old and New Leaves of the Myrtus Type, *Bot. Gaz.* (1904), **38**, 446. "The leaves of six out of the eight species studied transpire more for equal areas when fifteen to eighteen months old than they do when they have just reached their maximum area (i. e., at three or four months)."

In observing another leaf, the intervals at the same time were respectively fourteen and eighty-two minutes, the ratio being practically the same. The effect of the passing of a cloud before the sun was observed very many times; it naturally varied with the depth of the shading. In similar cases the test by weighing shows a depression in transpiration, but I could detect no additional one to be ascribed to the higher humidity.

It is clearly in large part because the direct sunshine heats the leaf above the temperature of the surrounding air that the transpiration is so much more rapid in it than in the brightest diffuse light. The following table shows the extent of this overheating. The temperature was determined by tying a leaf backward around the bulb of a thermometer:

Hour.	Temperature.		
	In shade.	In sun.	In leaf.
	°	°	°
7 a. m.	20.3	21.8	21.9
8 a. m.	24.3	25.2	27.4
9 a. m.	26	30.7	33.1
10 a. m.	26.9	32	35.4
11 a. m.	27.8	31.5	[a]34.7
12 m.	28.3	31.7	37.7
1 p. m.	28	30	[b]31.5
2 p. m.	28.5	31.5	38
3 p. m.	28.8	31	36.7
4 p. m.	28.6	30.6	36.4
5 p. m.	27.7	30	34
6 p. m.	26.6	27.6	28.5

[a] Light cloud. [b] Cloudy.

How great a difference in evaporation, as a merely physical process, these differences in temperature will exert is shown by a consideration of the variation in the tension[23] of water vapor with changes of temperature. Thus, at noon the temperature in the shade was 28.°3; at this point the tension of water vapor is 28.560 millimeters; at the temperature of the exposed leaf, 37.°7, the vapor tension is 48.463 millimeters; at 11.30 a. m., with a temperature 28.°4, the relative humidity was 66. The tension of vapor in the air at that time was 18.89 millimeters, making a relative humidity for the temperature of the leaf of only 39; the unsatisfied possible tension of vapor in the air was 9.69 millimeters in the shade, while it was 29.583 millimeters for the leaf.

The actually observed excess of transpiration in strong, direct light over that in the shade was greater, as a rule, than that of evaporation from a water surface under the same temperature conditions; the change from a light haze, under which the leaf is already somewhat overheated, to full illumination, frequently multiplying the rate of transpiration by four. This extra effect may in part be due to the action of the stomata, and must in part be ascribed to the expansion of the gas in the intercellular spaces, with the consequent ejection, as the leaf is warmed, of a portion

[23] *Tables* of Landolt and Bernthsen.

of this gas loaded with moisture. Of course, the opposite change in the volume of this included air would take place as the leaf cools.

It was impossible for me to make observations of any great value on the influence of the wind, because I could not regulate or measure its velocity. With a good subject, the concomitant use of the cobalt test and the weighing method should make it possible accurately to analyse the wind's influence, showing how much is due to mechanical agitation and how much to the constant change of the air outside. But no work on the coconut is sufficiently accurate and reliable for such an analysis. As was to be expected, the wind made a much greater difference in the transpiration of the leaves which were exposed to the greatest illumination than it did in that of the shaded ones. Thus, in one instance, the transpiration in direct sunshine was four times as great in a wind I estimated to be at 5 miles an hour as it was in a calm; but the increase was usually not more than 100 per cent. In the shade, a wind of this velocity added less than 50 per cent to the transpiration. I was unable to cut off the wind from a shaded plant without further interference with its illumination.

Any estimate of the total water transpired by entire trees can not be more than a rough approximation, because, aside from all possible inaccuracies in the observations on individual pinnæ, different days and seasons are unlike; and different neighboring trees, as well as different parts of the same individual, interfere with each other's transpiration. For these reasons any estimate based on observations made entirely in direct light must be too high. As already stated, some calculations obtained in this way are as high as 75 liters per diem. In the experiment from which the estimate of 28 liters was obtained the pinnæ were under as normal conditions as possible, taking their share of shading with the other pinnæ of the tree and being under check by observations on pinnæ in the natural position. The day was bright, but was not quite cloudless, and not especially warm.

At the rate of 28 liters per diem the annual transpiration is 10,220 liters. In this volume of water the plant takes up the mineral food to be used in its permanent growth and enough more to cover the annual loss in the nuts and cast leaves. The amount of mineral food permanently bound up in the growth of the stem and roots can not be very considerable, and that in the roots which die is already in a place to be absorbed again. The average dry weight of a fallen leaf may roughly be put at 3 kilograms, of which 8.5 per cent is ash and nitrogen. Allowing a fall of 16 leaves per annum, the loss of matter taken up in solution by the roots is 4,080 grams. In each nut the tree loses ash as follows:

	Grams.
In the husk	33.84
In the shell	3.36
In the copra	13.83
In the milk	5.97
Total	57.02

If the tree produces but 20 nuts per annum, which is more than the recent average at San Ramon, the loss of mineral matter in these is 1,140 grams and the total loss in leaves and nuts 5,220 grams. If this were absorbed in 10,220 liters of water the concentration would be 0.051 per cent. This is considerably above the average concentration to be found in ground water, as determined by analyses from water in wells and springs, but as a general proposition the water in intimate contact with the ground particles, and, when there is but little water in the soil, all of it, will be more concentrated than that which will run freely from wetter ground; and the valuable mineral food of plants is absorbed from such dilute solutions in greater proportion than is the water in which it is dissolved.

Effect of drought.—The season during which I carried on my work at San Ramon was characterized by extreme dryness, and this condition has interfered with my study of the plant's normal physiology, but at the same time it has given me an opportunity to observe the injury done by the abnormal conditions. The following table contains my measurements of the rainfall for this year and Mr. Havice's for the corresponding months a year ago:

Month.	1904–5.	1903–4.	Relative humidity, 1904–5.
	mm.	*mm.*	*Per cent.*
November	(15–30) 91.5	(1–30) 208	79.9
December	2.5	260	79.2
January	30	32	75.65
February	1	431	72.35
March	0	232	75.43
April	12.5	92	74.9

The third column gives the average relative humidity at or near the beach at 11.30 a. m. for November and at noon for the remaining months. Details as to the rainfall and humidity during my work are presented in the appendix to this paper. While the dryness of the air certainly has some direct effect on the coconut trees—for example, in influencing the movement of the hinge, without regard to how well the roots may have been supplied with water—I do not believe that serious damage is ever done to the tree except by the dryness of the ground. In other words, *trees judiciously irrigated have nothing to fear from a drought, however severe.*

The cultivated part of the San Ramon farm is well supplied with ground water, which, as a rule, finds the surface through a number of large springs. Two months after the drought began, some well-cultivated spots were still wet from below every morning. During November, December, and January, I frequently examined the young tips of roots, and through these months there was no important change in the condition of the ground and accordingly none in the roots. After the latter

part of December there was a rapid drying back of the streams running to the farm from the mountains, and the desiccation of the ground became rather abruptly evident a month later. Through January, surface cultivation kept all but the most porous ground in good condition, but after this time it was practically useless so far as the soil was concerned. By the middle of March the soil, where it was not sandy and ready to crumble, was as hard as if baked, and under the thoroughly cultivated surface it was full of fissures as much as a centimeter in breadth. The hardness was shown by the behavior of main roots nearly 1 centimeter in diameter, to whose disposition to grow in a straight line the tree owes its firmness. These, upon entering the cracks, turned almost at right angles and started to follow them.

In such a soil it is obvious that, in a short time, growth will be suspended. On March 21, I was unable to find any roots apparently normally active. The cessation of growth had been accomplished, or initiated, by the shortening of the growing region until the hardened hypodermis had advanced to within the root cap, obliterating the white absorbing surface. The disappearance of the absorbing region in the small branch roots, with short caps, was at first less complete, but by April 11 that portion remaining unlignified at the tip even of these was more or less flaccid, even in the early morning.

The turgor in the cortex of these roots equals nearly 0.4 normal potassium nitrate. Approaching the meristem it is higher, probably 0.5 normal. In the cap and epidermis I was unable to determine it. It will be noticed that the increase in turgor caused by desiccation and cessation of growth is more than half what it is when the cessation of growth and immersion in 0.5 normal potassium nitrate act together. This shows what proportion of the increase in the latter is directly due to the absorption of the salt.[24]

Of course, the roots of a tree do not all suffer alike, because different strata of the soil do not become equally dry. I tested the amount of moisture in the soil on April 11, at depths of 20, 60, and 100 centimeters, determining the weight lost by drying at a temperature of 40.3° C., the dew point being 25.5° C. The loss was—

At depth of—	Per cent.
20 centimeters	16.6
60 centimeters	21
100 centimeters	[25] 23.2

[24] For the influence of rather concentrated solutions on the turgor of immersed roots, see Stange, in *Bot. Zeit*, 1892. For the influence which the mechanical prevention of growth exerts upon the turgor, see especially Pfeffer, *Ueber Druck- und Arbeitsleistung*, 1893. For a general treatment of the dependence of the turgor upon the rate of growth, see my paper, *Ueber den Einfluss von Licht and Temperatur auf den Turgor, loc. cit.* 1896.

[25] The difference in *available* water is much greater than these figures would indicate, for at 20 centimeters in depth the soil is the hard clay already mentioned, while at 100 centimeters it is a sandy loam, crumbling readily; at 60 centimeters it is intermediate in character.

A very large part of the roots of the coconut grow in the stratum between 20 and 50 centimeters, and a tree to which water is available only at a greater depth must suffer. If conditions exist which permit roots to grow only at a greater depth, the obvious result will be a larger proportion in this deeper situation; in this way trees growing in dry places adapt themselves to their environment. However, *trees which are compelled to adapt themselves to unfavorable conditions of any description can not be expected to be prolific.* This is well illustrated by the dearth of nuts on the *Cocos*-clad hills about Romblon and Masbate. The water which can be drawn from a dry soil contains a greater proportion of mineral substances dissolved in it than that which is available when the soil is wet, so that the proportion between the quantity of available mineral food and the amount of water absorbed is not constant.

The shoot suffers from the inactivity of the roots. The influence of the drought on the growth of the leaves, and on the action of the hinge, has already been shown. The leaflets, which under these conditions are more folded, absorb less light, so that the leaf area which the tree has at its disposition is less efficient in photosynthesis. A normally active tree produces from twelve to twenty-four or more leaves a year. After December, during this drought, no new leaves appeared on trees which were less than 2 years old, and not more than one on any tree less than 5 years old. As a general rule, the older the tree the later it begins severely to suffer, the probable cause being that its roots run deeper than do those of the younger ones; but the growth of the leaves of individuals of all ages was very evidently retarded during February. This, in itself, would result in a decrease in the number of leaves borne at one time; but another factor is at least equally efficient in bringing about this result. The old leaves of the coconut are cast in a succession which, in adult trees, normally keeps pace with the appearance of the young ones, so that the number present at any one time does not materially vary. The internal factors causing the fall of the leaves have never been investigated, but there is no doubt that dryness is one of them. The "physiological dryness" caused by the outside drought naturally finds expression in a more rapid aging and falling of the leaves. In fact, the first, and for a long time the only, noticeable symptom of dryness is the number of leaves pendant or falling. It has already been noted that trees without a rather indefinite minimum number (say, twenty) of leaves, have not the vitality which is necessary to ripen nuts. An individual with only approximately this number will naturally not bear many. A retardation in the production of leaves and an acceleration in their loss, when acting together, will rapidly bring even the strongest trees toward this limit.

The flowering branches are formed in the axils of the leaves, and the formation of fewer of the latter must in itself ultimately result in the growth of fewer of the former. However, in practice, the development of these branches themselves is dependent, like any other growth, on a

sufficiency of water; it is arrested at the same time as is that of the younger leaves, long before the ones formed during the drought would bear flowers on their axillary branches, even in the most favorable weather. Thus the number of branches whose pistillate flowers were "opened" on a certain tree during the six months ending with April, 1905, was six, whereas during the preceding six months it had been nine. The flowers do not open until more than six months after the first appearance of the subtending leaf.

The number of nuts which can be borne depends upon the number of fruiting branches, and on every branch there are more pistillate flowers than can possibly give rise to mature nuts. The number which develop is a matter of individual difference between the trees; some regularly bear as many as ten, others never more than three. My observation of mature trees has not shown that the drought exercises any influence on the number which blast. It has seemed to me that in a grove in which the trees are in the first year or two of bearing a somewhat larger proportion than usual was blasting during the drought, but then it is also true that a very large percentage always do blast on such trees (on the first branches no nuts mature), so that this effect is uncertain. Neither have I been able positively to determine that the drought exerted any influence on the rapidity of the ripening of the nuts. If there is such an influence it will be toward a more rapid ripening, the tree thus producing smaller nuts, with less store of food. The records of the San Ramon farm show the number of nuts *cut* and the number of nuts and amount of copra sold, but they do not show how many nuts have been picked up from the ground nor at what times nuts have been used for seed; and these items are so considerable that I can draw no sufficiently accurate conclusions as to the yield of copra per nut.[26]

The direct result of the checking of the growth of the young leaves and flowering branches will be a deficiency in the yield of nuts, beginning not less than nine months after the drought first makes itself felt (nine months being about the minimum time between pollination and maturity) and ending at least eighteen months after the drought is broken (that being the usual time elapsing between the appearance of a leaf and the maturing of the subtended nuts).

There are other considerations which make it necessary to extend this period of depression in both directions. When more than a minimum number of nuts are borne on a branch the latter itself is unable to sustain the weight, so that the additional support must be furnished by the petioles of the lower leaves. The untimely casting or depression of these leaves withdraws this support and leaves the branches carrying the greatest load in a condition in which breakage is likely to occur. The nuts

[26] Judging by the eye alone, I can say positively that the nuts cut during April, 1905, averaged distinctly smaller than usual.

are heaviest about three months before maturity, and the loss by premature falling becomes considerable within five months after a drought first becomes serious. At about the same time the drought makes itself felt in injury to the crop through another channel. At all times some nuts are destroyed by crows, but the loss is usually inconsiderable. However, in a period of drought, when other food is scarce and the water courses are dry, they concentrate their attention on the young coconuts and accomplish no little destruction.

The injury to the tree's vitality during a prolonged drought is so severe that the return of favorable weather conditions is but slowly followed by the resumption of the normal activity. When rains come, the roots must awaken from a state of defensive rest in which a prompt response can not be expected. The partly folded condition of the pinnæ, induced by the dryness, seems permanently to remain; at any rate, recovery from it is very slow. A tree which through unfavorable conditions has only twenty-five leaves remaining has not the strength, even under the best conditions, at once to return to the formation of new leaves at the rate which is necessary for the maintenance of a head of thirty. Recovery after a drought is a building-up process, and it must be a slow one. It can hardly be complete in two years, and the return to the normal crop of ripe nuts which can be produced during uninterrupted good seasons can only be well under way in this time.

There is no record of the rainfall at San Ramon prior to September, 1903. The beginning of that year was a period of drought, like the one which has characterized the early months of 1905, but the former can not have been as intense as the latter, for the springs did not so completely disappear. The following record of the number of nuts cut shows how gradually this drought made itself felt and how prolonged its effects have been.[27]

January, 1903	55,160
May, 1903	50,000
August, 1903	45,000
November, 1903	40,723
February, 1904	30,637
May, 1904	33,800
August, 1904	39,765
November, 1904	30,208
February, 1905	31,972
May, 1905	61,550

The report of the superintendent of the farm for June, 1902, states that there were at that time 5,722 coconut trees in bearing on the farm and that 1,809 trees should begin to bear within two years from that date.

[27] The nuts are cut every three months. The work is done by contract, at the rate of 2 pesos per 1,000. This record is made from the "general-expense vouchers" for the expense of cutting.

With this increase in the number of trees, without any improvement in their yields, if there had been no drought, the total cut of nuts for 1904 should have been over 300,000; the actual number was 134,410. The record just given shows that the period of depression which followed the former drought was identical in character with the one to be anticipated from the present condition of the trees. The first real step in return to a fit yield was the cutting of May, 1905, about two years after the former drought ended; the return can not go much farther before the effects of this drought will head it off.

It is then the experience at this farm that a "dry season" occurring only every other year will constantly keep the yield of nuts at considerably less than half of what it would be if the supply of water were always sufficient for the tree's needs. It is obvious that a coconut plantation will be a probable source of continual profit only in localities where dry seasons may never be expected or where it is feasible by irrigation always to keep the ground sufficiently moist to enable the roots to preserve their full, normal activity.

CONCLUSION.

We have just seen that a considerable supply of water must constantly be at the disposal of the coconut, or it will protect itself against injurious desiccation by a partial suspense of its vitality. The necessity of this water as the carrier, in solution, of the plant's mineral and nitrogenous raw food has previously been touched upon. I made no direct experiments in the fertilization of the coconut, but it is the unanimous experience of those who are acquainted with the subject that an increase in some of the constituents of its mineral food has a very marked favorable effect on the production of the fruit.[28] At San Ramon certain trees are pointed out as particularly productive because they have long received the waste from the kitchen. The quantity of mineral food which the tree takes is roughly proportional to the amount of water which it absorbs.[29] Increasing the plant's transpiration has, then, the same effect

[28] Experiments with the object of determining whether the soil surrounding the coconut roots contains nitrifying organisms were undertaken by Dr. W. B. Wherry, of this Bureau. Unfortunately Dr. Wherry left Manila before the work could be completed. Indications of nitrification were not lacking in his work, which is sufficiently encouraging to be continued. The assistance of nitrifying organisms would be a material advantage to the coconut, although it has been shown above that the amount of water which the tree takes up and transpires would, even in such poor soil as that encountered along the beach, contain a sufficient quantity of inorganic constituents to allow the plant to thrive.—P. C. F.

[29] It is true that in a wet soil the food is in more dilute solution than in a dry one, but this is partially compensated for by the selective absorption of nutrient salts from very dilute solutions, the solution absorbed being more concentrated than that in the ground. The more dilute the solution the greater is this selective power.

as applying a fertilizer to the ground. The amount of transpiration can be increased in two ways—by increasing the amount of water at the disposal of the roots and by improving the conditions for its evaporation from the leaves.

In seasons of drought the first method does the plant a double service, for the water which is artificially furnished is not only valuable in itself but also because of the substances dissolved in it. However, during other seasons, irrigation may not merely be useless but even very injurious, for ground too wet does not favor the activity of coconut roots any more than that which is too dry.

We have seen that the transpiration of the coconut is somewhat accelerated by the wind, and greatly so by intense illumination. Therefore, so long as the roots are not in too dry a soil, it is in the plant's interest to be exposed as much as is normally possible to these two agents. On any considerable tract devoted to coconut culture this can be done in but one way—by not planting the trees too close together. I have never seen a grove in which the trees were sufficiently far apart so that, unless other conditions were very unfavorable, the trees around the outside were not much more productive than those in the interior. At San Ramon, a considerable proportion of the trees are planted in double rows, one row along each side of a narrow road. In such a row, which contained no nonbearing trees, I found the yield at one cutting to average 22 nuts to the tree. A row of trees along the well-drained bank of a slough yielded an average of 27 nuts, all trees producing. A single tree standing by itself in the open yielded 55 nuts. In the interior of an old grove, the average for the producing trees was about 11, and in the same situation in a large one on the neighboring hacienda of Talisayan the average for bearing trees was only 8; the individuals in the area where this count was made were as a rule about 18 feet apart, their crowns interlaced freely, producing a rather dense shade, and many trees were without ripe nuts.

I have no doubt that up to a distance of at least 15 meters any increase in the intervals between trees will result in an appreciable advance in the average yield per tree, but by planting beyond the intervals at which the interlacing of roots and of leaves would bring the trees into keen competition for water and light, and would also largely break the wind passing through the crowns, the increase in the yield of nuts for the individual trees would not be commensurate with the area of land in use. In my opinion, the trees in a grove can usually best be placed at intervals of about 9 meters. In exposed rows they may well be closer together, and where intense cultivation is economically possible the distance between them may be a little less.

The natural habitat of the coconut is the strand. It is restricted to this because it bears fruit too large to be practically transportable by any

other natural agent than the water; and it is adapted thereto by possessing superficial roots which are uninjured by temporary exposure to concentrated solutions, by having a tough, very elastic trunk, and by producing leaves which are not merely tolerant of the most intense insolation and wind but which are unable to work to the best purpose without more light and wind than many plants can endure. As is true for every cultivated plant, it is possible to create for the coconut conditions altogether more favorable for its utmost thrift than are ever known to occur in nature. It naturally grows in a "poor" soil—that is, in one in which its mineral and nitrogenous raw food is present in very dilute solution. We can improve its environment in this respect, and can profitably carry this improvement much further than is the general practice at present. But the coconut must not be expected to thrive, even in the richest soil and with the best cultivation, if its supply of light is restricted by other trees or in any other way, or where the air is too still or an adequate supply of water is not always available near the surface of the ground.

There is another method of increasing the yield of coconuts, slower but more permanent than improved cultivation; this is by the selection of seed. I have done nothing with this subject, and only mention it because the results of selection can not appear for many years, and a mistaken method would be long in showing its uselessness. Nuts obviously should be selected for seed from trees conspicuous for the amount or quality of their yield. It is usually not a difficult matter to decide whether or not the tree's superior yield is due to its growing under exceptionally favorable conditions. If it is, it shows how other trees may be made to bear equally well, but there is no reason for selecting the nuts of such a tree for seed; its offspring can not be expected to bear more nuts under ordinary conditions than the parent would have done without its exceptional advantages. The environment is not hereditary. The tree the nuts of which should be used as seed is the one the production of which is great in proportion to its opportunity. A tree bearing regularly 12 nuts to the cutting under conditions which allow its neighbors but 8 should have its nuts saved for seed in preference to those of an individual having 30 nuts among equally productive neighbors.

Hygrometer readings, San Ramon farm.

NOVEMBER, 1904.

Date.	Beach.									
	6 a. m.			12 m.			4 p. m.			Rainfall to 4 p. m.
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
15							25	23.6	89	27
16	23.6	23.1	95	24.1	23	91	23.1	22.9	98	16
17	23.9	22.1	85+	25.5	23.5	85	24.9	23.8	91	3.5
18	24.5	23.7	93	26	29.5	88	26.3	24.6	87	29
19	24.2	23.8	97	27.5	26.6	95	26.2	24.2	85	7
20	25	23.8	91—	29.1	25.5	75	29.1	26.4	80	Trace.
21	24.8	23.2	91—	29.8	27.3	82	28.5	26.3	84	Trace.
22	24.5	23.4	91	28.9	26.1	80	28.6	25.7	79	Trace.
23	27.9	25.4	81	28.6	25.4	77	24.3	23.4	93	9
24	24.5	23.5	91—	29.7	25.7	72	26	24.5	88	0
25	24.6	21.6	78	23.6	24.6	72	28	24.6	76	0
26	25	23.4	87	29	23.3	62	29.6	24.1	63	0
27	23	21.2	84				27.5	24.2	76	0
28	21.2	20.2	91							
30							27.9	24.8	79	0
Average			88.8			79.9			83.3	91.5

Date.	Interior.								
	6 a. m.			12 m.			4 p. m.		
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*
15							24.5	23.3	90+
16	23	22.5	95+	23.2	22.9	98	23	22.9	99
17	23.9	22.5	87	25.3	23.1	83	24.5	23.3	91—
18	23.5	23.2	98	24.5	23.5	92	25	24.2	93
19	24	23.5	96	28.5	25	75	25.5	24.5	91
20	27.5	23.4	91—	29.4	25.5	73	28	25.5	82
21	24.3	23	89	28.4	25.7	80	27.5	25.2	83
22	22.5	22	95	28.3	25.7	80	28.4	25.6	80
23	26.9	24.5	81	29	26	78	23.5	22.8	94
24	24.5	23.4	91	28.9	25.4	76	25.9	24.5	89
25	23.9	22.6	89	29	24.5	69+	26.2	24.4	85
26	23.8	23	93	28.5	24	69	28	23.5	69
27	21.8	20.8	91	29.4	25		27.2	24.5	80
28	21	20.2	93						
30							27.8	25.2	81
Average			91.5			81.2			87.6

Hygrometer readings, San Ramon farm—Continued.

NOVEMBER, 1904—Continued.

Temperature and humidity.	Averages.		
	Beach.	Interior.	Difference.
Temperature:	°	°	°
6 a. m	24.3	23.7	−0.6
12 m	28	27.5	−.5
4 p. m	26.8	26	−.8
Humidity:	*Per cent.*	*Per cent.*	*Per cent.*
6 a. m	88.8	91.5	+2.7
12 m	79.9	81.2	+1.3
4 p. m	83.3	87.6	+4.3

DECEMBER, 1904.

Date.	Beach.								
	7.30 a. m.			11.30 a. m.			4 p. m.		
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*
1	22.6	21.6	92	26.4	24.5	85	27.9	24.6	76
2	25	22.3	79	29	24	66	26.2	23.9	83
3	27.2	23.6	74	28.5	24	69	27.6	23.5	72
4	24.3	22.7	87				28	24.2	73
5	25.5	22.6	78	28.8	23.7	65+	29.1	24.5	68
6	27.4	24.1	76	27	24.3	80	28	25.1	79
7	26.4	24.4	85	28.3	25.5	80	27.2	25	84
8	25.1	23.2	85	28	26	86	28.3	24.8	75
9	25.3	24.1	91	28.9	25.9	78	27.8	25.5	83
10	26.9	24.5	81	28.5	26.3	84	27.6	25.5	85
11							27.3	25.3	85
12	26.2	24	83	29	26	79	28.1	25.5	81
13	26.4	23.7	79	27.7	24.8	79	28.5	25.5	78
14	26.2	24.3	85						
15	26.8	25.7	92	27.7	25.5	84	28	25.6	83
16	26.5	24.7	86	28.1	26.1	82	29.5	27.2	84
17	25.7	23.9	86	29.1	25.3	73	28.9	25.5	76
18	26.5	23.9	81				28.2	26.3	87
19	25	23.6	89	28.6	25.3	77	27.5	24.8	80
20	25.5	24.4	91	28.3	25.2	78	26.3	24	83
21	24	22.7	89	27.5	25.4	85	27.2	25	84
22	25.3	23.7	87	27.5	24.2	76	27.7	25	78
23	25.9	23.7	83	28	25.5	82	28.5	25.9	81
24	25.7	24	87	27.1	24.8	83	26.6	24.6	85
25	25.6	24.2	89	27.7	24.8	79	26.9	24.7	83
26	24.4	22	80						
27	26.3	24.6	87	27.4	25.3	85	26.8	25.4	89
28	26.7	24.3	82	27.3	25.1	84	27.6	25	81
29	25	22.5	80						
30	26.5	24	81	28.5	25.1	76	28.1	25	78
31	26.2	24	83	27.2	25.2	85			
Average			84.27			79.2			80.52

Hygrometer readings, San Ramon farm—Continued.

DECEMBER, 1904—Continued.

Date.	Interior.									
	7.30 a. m.			11.30 a. m.			4 p. m.			Rainfall.
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
1	22.5	21.9	95	26.5	24.6	85	26.4	25	89	Trace.
2	25	22.8	83	28.7	25.4	77	26.5	24.7	86	0
3	28.3	25.2	77	28.7	25.6	78	27	23.5	74	0
4	24.3	23	89	------	------	------	27.2	24.2	78	0
5	25.5	22.5	77	28	24	72	28.1	24.1	72	0
6	28	24.4	74	27.9	25	79	27.2	23.9	83	Trace.
7	26.9	24.5	82	28	25.8	84	26.8	25	86	Trace.
8	25.9	24.2	87	28.6	26.1	82	27.5	25.1	83	0
9	24.9	24	93	30.6	27.5	78	27.5	25.7	87	Trace.
10	26.3	24.5	86	27.9	25	86	27.5	25	82	Trace.
11	------	------	------	------	------	------	27	25	85	0
12	26.1	24	84	27.9	25	79	27.6	25.4	84	0
13	26.3	24	83	28	24.3	74	27.9	24.9	78	0
14	26.5	24.6	85	------	------	------	------	------	------	0
15	25.4	23.5	85	27.6	25.4	84	27.5	25	82	1
16	28	25.6	83	27.6	25	81	28.3	25.7	81	Trace.
17	25.3	23.9	89	27.8	24.5	76	28.1	25	78	0
18	26.6	24.2	81	------	------	------	27.6	25.5	87	Trace.
19	25.8	24.2	87	27.6	25	81	27.5	24.3	77	Trace.
20	25.5	24.6	93	28.5	25.6	79	26.2	24.3	85	1
21	23.7	23	94	28.4	25.4	78	27.3	24.8	82	Trace.
22	24.8	23.3	88	27.6	24.2	76	27.4	24.7	80	Trace.
23	26.5	24	81	27.5	25.2	84	27.4	24.8	81	0
24	25.1	23.3	86	27.2	24.2	78	26.2	24.4	86	0.5
25	25.1	24	91	27.5	24.5	78	26.5	24.5	85	0
26	24.1	23.1	91	------	------	------	------	------	------	0
27	26.8	25	86	27.2	25.1	85	26.7	24.6	84	0
28	26.8	24.5	83	27.9	25.3	81	27.6	24.4	77	0
29	25.5	22.9	80	------	------	------	------	------	------	0
30	27.7	24.1	74	29.6	25	69	27.5	24.5	78	0
31	27.1	24.9	83	28.5	25.5	78	------	------	------	0
Average	------	------	85	------	------	79.28	------	------	81.85	2.5

Hygrometer readings, San Ramon farm—Continued.

JANUARY, 1905.

Date.	Beach.								
	7.30 a. m.			11.30 a. m.			4 p. m.		
	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*
1									
2									
3	26	24.1	85	29.4	24.2	65	27.5	24.5	78
4	26	24.3	87	28.6	24.5	71	26.6	24	80
5	24.8	23	86	27.5	23.9	74	27.1	24	77
6	27.6	24.2	76	27.5	25	82	27.1	24.8	83
7	25.7	23.2	81	28	23.6	69	27.5	23.8	73
8	26	24.4	87				27	24.6	82
9	24.7	23	87	28.3	24.6	74	26.5	24.4	84
10	25.5	23.7	86	27.5	24.3	77	27.5	25	82
11	25.4	23.8	87	28.3	25.1	77	26.5	24.5	85
12	26.8	24	79	29.7	26	74	26.3	24.5	86
13	22.9	22.5	97	27.6	24.9	80	27.3	25.1	84
14									
15									
16				29.1	24.6	70	27	24.5	82
17	24.4	21.9	80	27.6	24.6	78	27.8	24.2	74
18	24.1	22.5	87	27.4	24	75	28	24.5	75
19	25.1	23.4	87	28.8	24	67	28	24.7	76
20	24.3	23.1	91	28	25.5	82	28.8	25.3	75
21	25.4	23.3	84	28	25.8	84	27	24.8	84
22	27.6	24.8	80				27.5	24.7	80
23				28.8	25.9	79	27.2	25.2	85
24	25.1	23.5	87	27.5	25	82	27.6	25.3	84
25	26	24.1	85	28	25.3	80	28.5	25.8	80
26	25.2	23.4	86	28.7	25.9	80	26.8	24.8	85
27	24.5	21.8	79	28.9	25.1	73	27.8	25.1	80
28	24.5	22.5	85	29.4	25.8	75	28.9	25.6	77
29									
30	25	22.5	80						
31				28	24	72	28.2	24.8	76
Average			84.74			75.65			80.28

Hygrometer readings, San Ramon farm—Continued.

JANUARY, 1905—Continued.

Date.	Interior.									Rainfall.
	7.30 a. m.			11.30 a. m.			4 p. m.			
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
1										0
2										0
3	26.9	24.4	81	29	24	66	27.3	24.1	77	Trace.
4	26.5	23.9	81	29	24.2	68	28	24.7	76	0
5	26	23.5	81	28	23.6	69	26.5	23.6	78	0
6	27.9	24.5	76	28.2	25	77	26.5	24.4	84	0
7	26.5	23.7	79	28.5	23.8	68	27.2	23.6	71	0
8	26.2	24.5	87				26.6	24.2	82	0
9	25.2	23.6	87	28	24	72	26.5	24.3	83	0
10	25.5	23.6	85	28.5	25.4	78	27.5	24.8	80	0
11	25.9	24.2	87	27.7	24.7	78	26.1	24.3	86	0
12	27.5	24.6	79	29.4	25.7	74	26.5	24.3	87	2
13	23.1	22.8	98	27	24.4	81	26.9	24.7	83	26
14										0
15										0
16				29.4	25.4	72	26.5	24.5	85	0
17	25	22.6	81	27.5	24.6	79	27.3	24.1	77	0
18	24.4	22.9	88	27.5	24	75	27.3	24.2	78	0
19	24.7	23.2	88	28.8	23.7	68	27.3	24.3	78	0
20	24.3	23.3	92	28.5	25.5	78	28	25	78	0
21	25	23.3	87	29	26.3	80	27	25	85	0
22	27.7	24.7	78				27.5	25.5	86	2
23				27.4	24.6	80	27.1	25.1	85	0
24	24.9	23.5	89	28	25	78	28	25.4	81	0
25	26.4	24.4	85	28.5	25.5	79	27.7	25	80	Trace.
26	25.6	24	87	28.6	25.6	79	27	25.2	80	0
27	24.7	22	79	28.7	24.9	73	27.5	24.5	78	0
28	25.6	22.5	77	29	25.4	75	28.3	25.2	78	0
29										
30	26.3	24	83							0
31				28	23.7	70	27.6	24.3	76	0
Average			84.13			74.65			80.60	30

Hygrometer readings, San Ramon farm—Continued.

FEBRUARY, 1905.

Date.	7.30 a. m.			11.30 a. m.			4 p. m.			Rain-fall.
	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
1	24.6	23	87	27.2	24.9	84	28.5	25	75	1
2	24.8	22.7	83							0
3	24.4	22.1	82	27.6	23.5	72	28.5	24.3	71	0
4	24	22.4	87	29.3	25	71	27	23.5	74	0
5	23.9	21.4	80							0
6	24.4	22.6	86	28.6	25	75	28.5	24.9	75	Trace.
7	24.1	22.5	87	29	25.3	74	28	24.5	74	Trace.
8	23.1	21.7	88	28.7	25	74	29	25.4	75	0
9	24	22.1	85	28.8	24.8	72				0
10	21.5	20.5	91	27.2	23.5	73	28.8	24.3	69	0
11	23	21.8	90	27.8	25.1	80				0
12										0
13	24.5	22.6	85	29	25	72	28	24.9	78	0
14	23	21	84	28.1	24.5	75	28.8	24.2	68	0
15	24	21.8	82	28	23.7	70	28.3	23.9	69	0
16	22	20.8	90	28.3	24.4	73	28.6	24.4	71	0
17	23.6	21.9	87	28.4	23.4	66	28	23.7	70	0
18	24.3	22	82	28.4	24	69				0
19										0
20	24.1	22.1	84	28.1	24	71	27.8	24	73	0
21	22.4	20.6	85	28.2	24.5	74	28.4	24	69	0
22	22.6	20.9	87	27.4	24	76	28.4	24	69	0
23	18	16.3	85	26.8	21	59	27.5	23.1	69	0
24	20.4	17.5	75	26.8	22.2	68	27.6	22.6	65	0
25	22.1	20.4	87	28.5	24.5	72				0
26							27.3	23.5	72	0
27	19.8	16.2	69	27.5	23.5	72	27.4	23.2	70	0
28	24.2	21.2	76	28.6	24.5	71	27.8	24	72	0
Average			84.16			72.35			71.4	1

Hygrometer readings, San Ramon farm—Continued.

MARCH, 1905.

Date.	7.30 a. m.			11.30 a. m.			4 p. m.			Rainfall.
	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	Dry.	Wet.	Relative humidity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
1	22.4	20.4	84	28.3	24	70	28	24.5	75	0
2	22	19.5	79	27.8	23.5	70	28.5	25	75	0
3	24.3	22	82	28.4	24.6	73	27.5	24.1	75	0
4	23.1	21	83	28	24.6	76	----	----	----	0
5	----	----	----	----	----	----	----	----	----	0
6	23.5	20.6	77	----	----	----	----	----	----	0
7	----	----	----	29.1	24.6	69	27.5	24.3	77	0
8	23.6	22	87	29	24.9	72	26.9	24.4	81	0
9	24.8	23	86	28.2	23.6	68	26.8	23.5	75	0
10	24	21.2	78	29	23.6	63	27.9	24	72	0
11	23.2	21.2	84	28.7	24.2	69	27.5	23.5	71	0
12	24.5	21.7	78	28.2	24.6	74	27.4	24.6	80	0
13	24	22.1	85	28.5	25.5	78	----	----	----	0
14	25.2	23.3	85	28.6	26	81	28.9	25.5	76	0
15	25	22	77	29	25.4	75	28.6	25.5	78	0
16	25	23	84	29.1	25.8	77	28.7	25	74	0
17	25.5	23.5	84	29	26	79	28	25.4	81	Trace.
18	24.7	22.9	86	28.6	26	81	----	----	----	0
19	25.8	23.8	85	29.8	26.3	76	29	26.1	79	0
20	26.1	23.8	83	29.5	26.4	80	27.9	25.7	84	0
21	24.5	22.5	84	29.5	26.5	79	28.9	26.1	80	0
22	26	23.4	80	29.5	27	82	29.2	25.9	77	0
23	26.5	23.9	80	29.1	26.3	80	----	----	----	0
24	25	22.8	83	29.3	26.5	80	29.8	26.4	77	0
25	26.2	23.3	78	29	25.9	78	28.3	25.8	82	0
26	----	----	----	----	----	----	----	----	----	0
27	26.7	24	79	29.7	27.1	81	29.7	26.5	78	0
28	27	24	78	29.6	26	75	----	----	----	0
29	26.2	23.6	81	31	27	73	29.8	26.3	77	0
30	27.4	24.6	80	29.3	26	77	29.8	26.1	76	Trace.
31	26	24.1	85	29.6	26.3	77	30	26.8	78	0
Average	----	----	81.96	----	----	75.46	----	----	77.30	0

Hygrometer readings, San Ramon farm—Continued.

APRIL, 1905.

Date.	7.30 a. m.			11.30 a. m.			4 p. m.			Rain-fall.
	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.	Dry.	Wet.	Relative humid-ity.	
	°	°	*Per cent.*	°	°	*Per cent.*	°	°	*Per cent.*	*mm.*
1	26.4	24.9	88	28.1	25.9	84				0.5
2										0
3				28.8	26.2	81	29	26	79	Trace.
4	27.1	24.5	81	31	27.6	77	30	25.9	72	0
5	26.9	24.1	79	30.5	25.3	66	29.3	25	70	0
6	25.6	23.8	86	30.6	26.2	70	28.9	25.5	76	0
7	26.6	24.5	84	30	25.9	72	28.9	25.3	75	Trace.
8	26.7	24.6	84	28.8	26	80	30.5	26.9	76	0
9	26.9	25.1	86	29.4	26.4	79	28.6	25.4	77	0
10	25	23.4	87	30.6	26.6	73	29.9	26.1	73	Trace.
11	25.2	23.2	85	28.9	26.2	80	28	26	85	3
12	24.7	23.6	91	28.9	26.1	80	29.4	26.5	80	Trace.
13	25.8	23.9	85	28.7	26.2	82	26	24.4	87	9
14										Trace.
15	26.1	23.8	82	29.3	26.4	79	30.7	26.2	69	0
16	26.7	23.8	77							0
17										0
18										0
19	27.2	24.3	78	29.4	26	75	28.6	25.5	77	0
20	26.5	24.1	81	30	26.8	77	28.8	26	79	0
21	27.2	25	83	29.8	25.9	72	30	26	71	0
22	27.7	24.9	79	29.6	26	74	29.3	26.2	77	0
23	26.3	24.2	83	30.6	26.2	70	32	26.7	64	0
24	26.8	23.3	73	30.7	26.1	68	29.9	25.9	71	0
25	27.2	24.3	78	31.2	27.4	73	30	26.6	75	0
26	26.6	23.9	79	30.1	26.3	73	30.4	26.3	71	0
27	27.3	24.8	81	31.1	26.6	69	29	26.7	83	0
28	26.9	24.1	78							0
29	26.6	23.7	77	32.2	27.3	67	32.3	27.9	70	0
30										
Average			81.875			74.9			75.32	12.5

ILLUSTRATIONS.

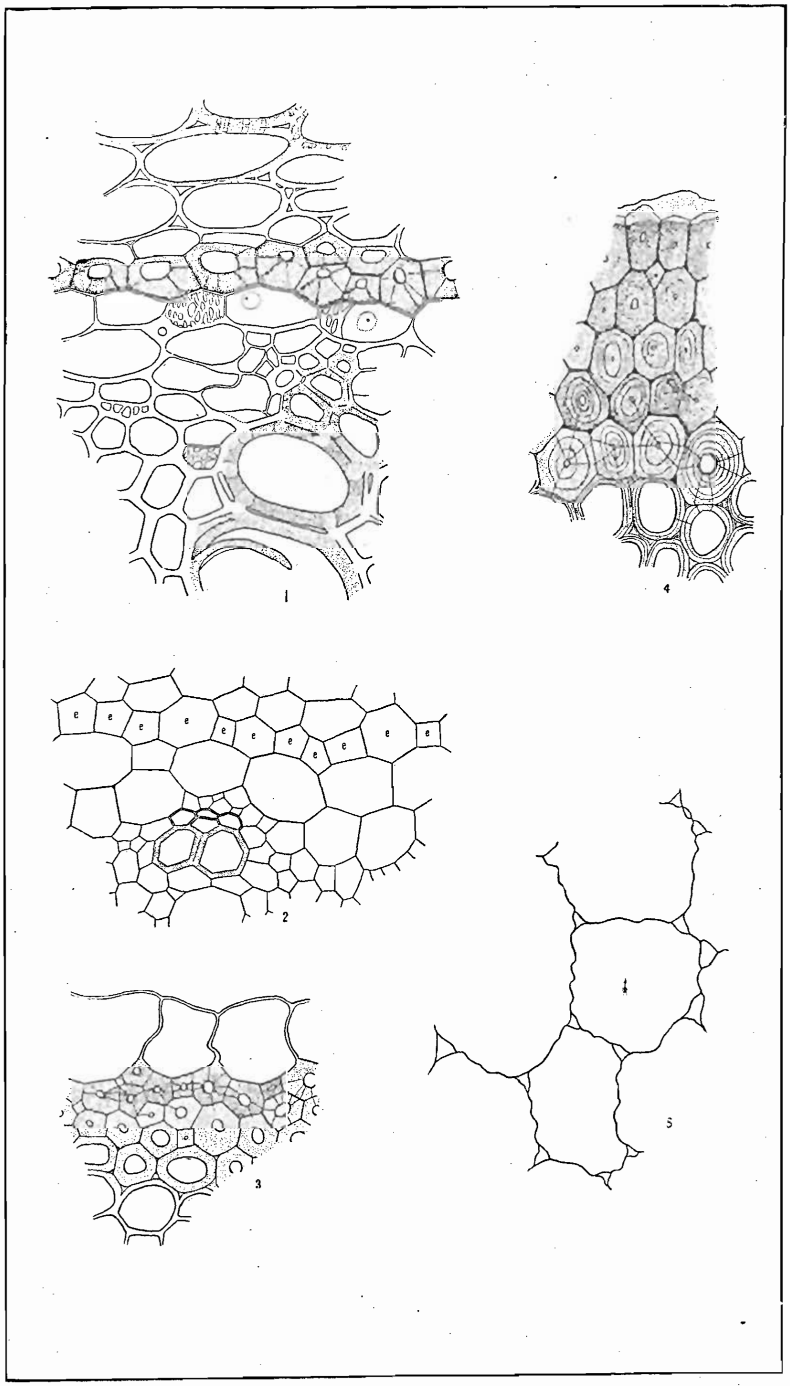

PLATE I.

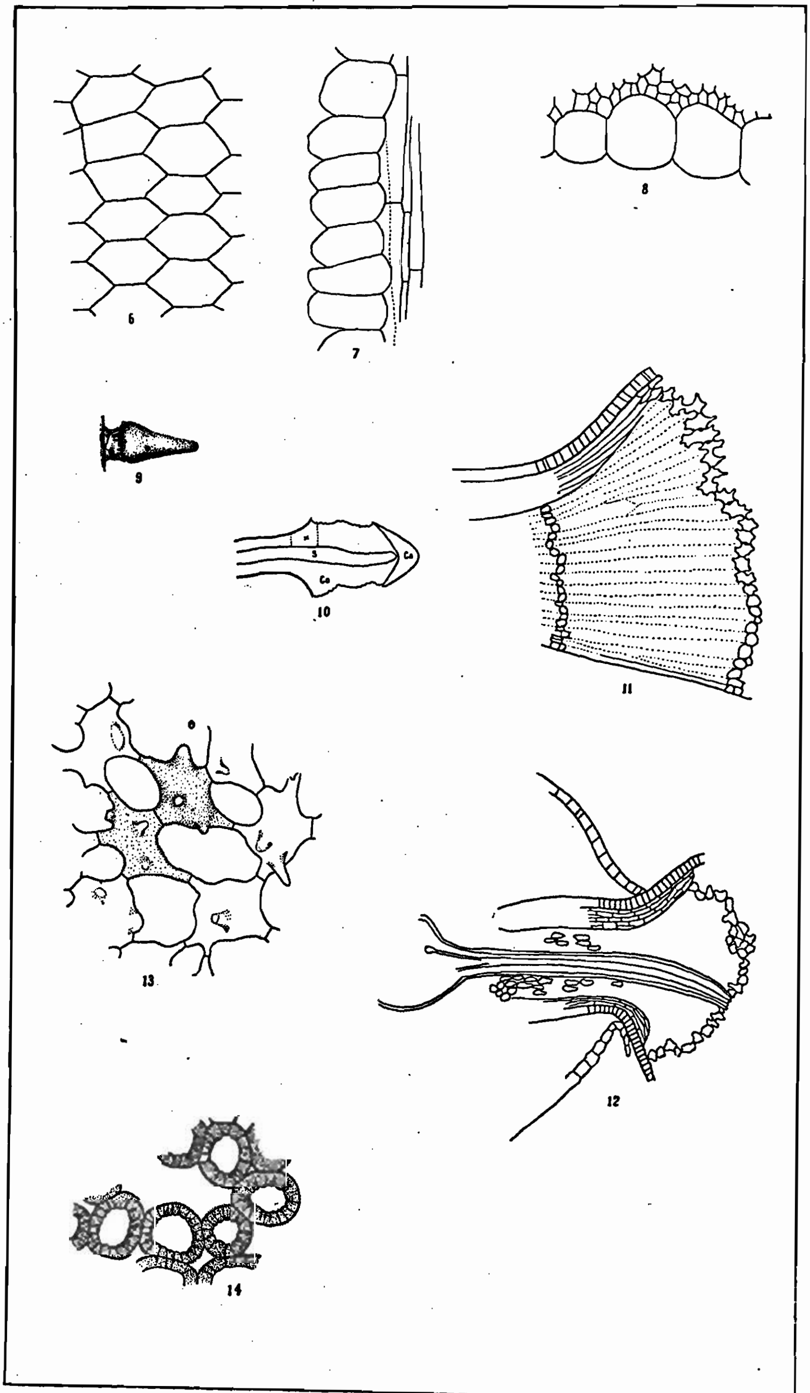

PLATE II.

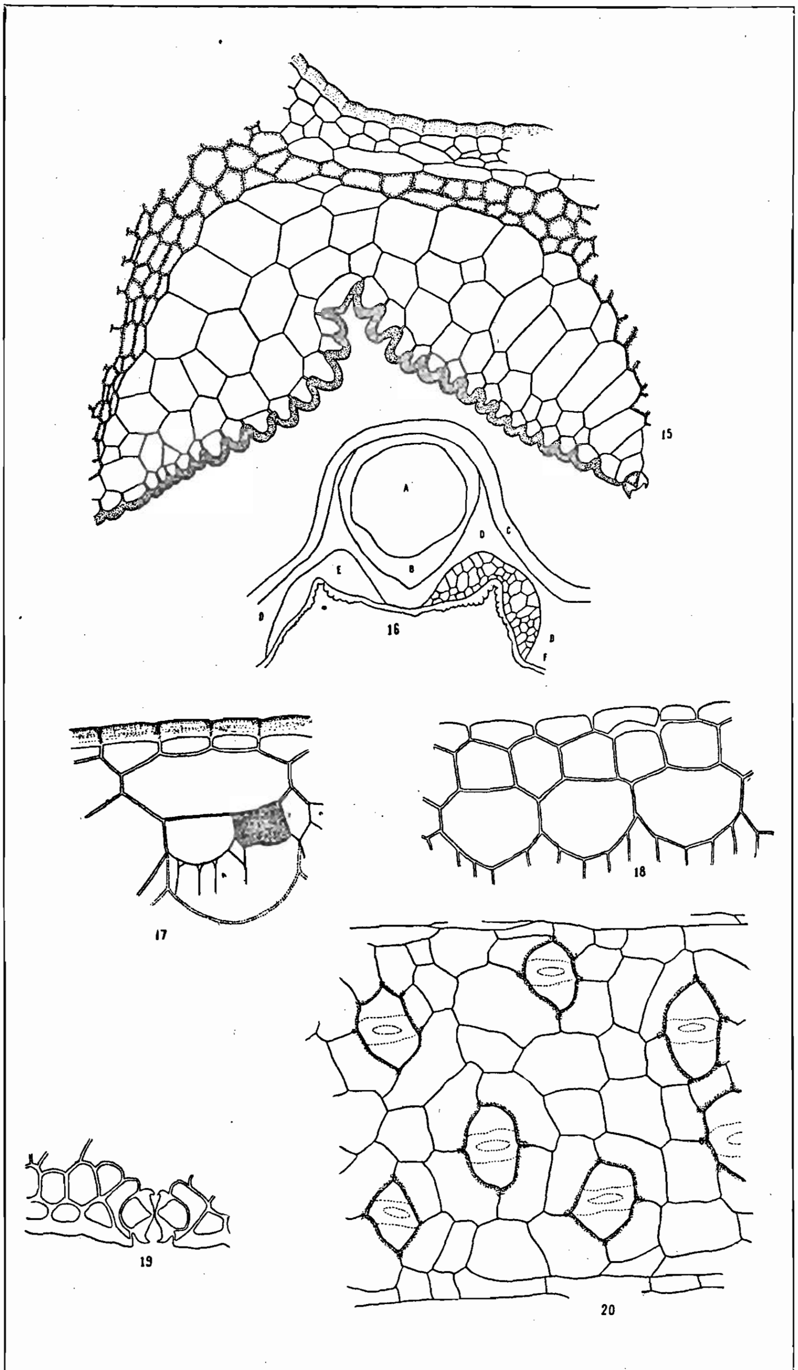

PLATE III.

THE COCONUT AND ITS RELATION TO THE PRODUCTION OF COCONUT OIL.

By Herbert S. Walker.
(From the Chemical Laboratory, Bureau of Science.)

THE SOIL.

Coconut production from the standpoint of the quality and quantity of the oil yielded has hitherto not been investigated, and it was decided to enter into this subject as fully as possible. The first problem which presented itself was the influence of the soil in which the trees grow on the yield of nuts, copra, and oil. It had been noticed for a long time that coconut trees growing near the seashore at San Ramon produced much more fruit than those standing farther inland, and it had also been stated that the former trees bear a better quality of nuts than the latter.

To determine how far these facts might be accounted for by a greater fertility of the soil near the sea, the following analyses were made of a number of soils in which coconut trees were growing, the samples being taken at the beach as well as farther inland, and two from Davao, where coconut trees flourish:

Analyses of San Ramon soils.

Sample.	Fine earth.	Moisture.	Loss on ignition.	P_2O_5.	K_2O.	N.	Fine earth, Cl.	Coarse earth, Cl.
	60 mesh.							
A_1	22.5	2.65	5.83	0.08	0.36	0.18	0.012	0.001
A_2	7	2.45	3.06	.07	.52	.03	.018	.002
A_3	23	1.99	1.68	.07	.55	.02	.009	.002
B_1	52	5.11	7.93	.33	.58	.13	.018	.001
B_2	37.5	7.82	5.97	.08	.45	.04	.004	.001
B_3	45	7.33	6.03	.08	.48	.03	.006	.001
C_2	3.7	2.55	1.53	.10	.88	.003		
C_3	2.1	2.65	1.45			.02		
	30 mesh.							
D_1	38	2.52	1.35	.11	.18	.01		
D_2	26.9	2.96	1.71	.11	.62	.004		
D_3	37.2	2.32	2.29	.07	.65	.01		
	40 mesh.							
E	43.6	7.6	1.79	.08	.40	.05		
F	85.7	24	6.04	.24	.21	.11		

Moisture on samples E and F determined at San Ramon; on all others at the laboratory, Manila.

Fine earth determined on original samples.

Loss on N, P_2O_5, K_2O determined and percentages calculated to original sample on soil dried at 100°–105°.

Soils marked "A" were taken at a distance of 60 feet from the sea, A_1 being the surface, A_2 18 inches, and A_3 3 feet below.

The B soils were taken from 2,800 feet inland, 40 feet above sea level, where trees were not bearing so well, and at the same depths as the A soils of corresponding numbers.

The C soils were from the same place as those marked "A," but were taken at a greater depth so as to reach the locality of the deepest roots, C_2 being from 4 feet and C_3 from 8 feet below the surface.

The D soils were taken from the same place and depths as the C soils.

Soil E was taken at a depth of 3 to 4 feet, 6 feet distant from a very healthy 5-year-old tree near the sea.

Soil F was taken at a depth of about 3 feet and about 1,800 feet from the sea, where trees do not bear so well.

Davao soils.

Sample.	Fine earth.	Moisture.	Loss on ignition.	P_2O_5.	K_2O.	N.	CaO.
	40 mesh.						
I	95	7.60	5.42	0.16	0.26	0.05	2.85
II	91.9	1.30	1.42	.11	.13	.03	2.06

Soil marked "I" was taken at a distance of 50 yards from the Davao River about 1 mile inland from the sea, where trees were growing well.

Soil marked "II" was taken at the mouth of the Davao River about 50 feet from the sea. In this location a few young trees were doing fairly well.

Both samples were taken at a depth of about 1 foot.

Chemically, the results of these analyses show very little difference between the soils near the shore and those farther inland. The latter, contrary to what would be supposed, were found to be somewhat superior to the former, although neither could be called extremely fertile. Chlorine was determined in the first six of these samples, with the idea that this element might play some part in the better growth of trees near the sea, but the amounts found were so small as to be almost negligible. From these results it is evident that the inferior quality of the inland trees can not be explained by the analytical difference in the soils; neither does the salt from the sea appear to an appreciable extent, even around those trees which are actually growing on the beach.

However, the superior growth of trees near the sea might well be accounted for theoretically by the physical characteristics of the soil alone. For example, the soil marked "E" in the foregoing table is practically nothing but a very porous sand which, at a depth of 3 feet, is completely saturated with moisture; while F is a very stiff clay, such as the Spaniards formerly used for making bricks. While it is true that the latter contains more total moisture and plant nutriment than the

former, the amount available to the tree is probably not by any means as great, owing to the difference in porosity.[1] In view of the large amount of water necessary to the life of the coconut tree, one would naturally expect it to grow better in an easily permeable soil rather than in one from which water and soluble nutriment can only be taken up with difficulty. The objection has been raised that according to chemical analyses the soils near the sea do not appear to contain sufficient plant food to support life of any kind, much less that of a large and heavily productive tree like the coconut.

From analyses of coconuts made at this Bureau we have found that nuts from San Ramon contain nitrogen, potash, and phosphoric acid in approximately the following amounts:

Part.	Nitrogen.	Potash.	Phosphoric acid.
	Grams.	*Grams.*	*Grams.*
Husk	1.609	3.915	0.017
Shell	660	.947	.459
Meat	4.683	2.475	1.740
Milk	1.542	1.313	.171
Total	8.494	8.650	2.387

In 1 hectare of land on which about 173 trees are growing and producing, a total of about 7,000 nuts per annum may be expected.[2] Under these conditions there is exhausted from the soil by the nuts alone a total of—

	Kilos.
Nitrogen	59.43
Potash	60.55
Phosphoric acid	16.73

In addition to this there is a large weight of material withdrawn by falling leaves. Each tree on an average will lose annually 16 leaves, weighing about 3 kilos each, making about 8,300 kilos per year lost by 173 trees. Analysis shows that in this weight of dry leaves there is, approximately—

	Kilos.
Nitrogen	31.69
Potash	74.82
Phosphoric acid	24.65

We have then a total annual drain on the soil per hectare of—

	Kilos.
Nitrogen	91.12
Potash	135.37
Phosphoric acid	41.38

[1] See the paper by E. B. Copeland on the character of the roots of the *Cocos*.

[2] This is on the basis of 40 nuts per tree per annum, a very high average for San Ramon trees.

Assuming these figures to be approximately correct, it would appear at first glance somewhat of a puzzle to determine how the tree manages to thrive and take up so much nourishment each year from a soil seemingly so devoid of fertility as that along the sea at San Ramon. However, when we consider the total amount of soil available to each tree, the problem becomes a simple one. The root mass of a coconut draws nutriment from a depth of at least 2 meters below the surface of the ground and outward on all sides for from 3½ to 6½ meters distance from its base. It thus comes in contact with an exceedingly large mass of material and it makes use of all the available nourishment therein.

In 1 hectare, or 10,000 square meters, of land there is available to the coconut trees planted thereon a total of at least 20,000 cubic meters of soil, or, if we allow a specific gravity of about two, 40,000,000 kilos.

From the table of analyses of San Ramon soils, we find that the soils near the sea average about as follows:

	Per cent.
Nitrogen	0.07
Potash	.50
Phosphoric acid	.07

In 40,000,000 kilos we have—

	Kilos.
Nitrogen	28,000
Potash	200,000
Phosphoric acid	28,000

From the amount taken from the soil in each year, even though no fresh addition were made, we can calculate the number of years required completely to exhaust this soil of its plant food as follows:

	Years.
Nitrogen	307
Potash	1,478
Phosphoric acid	677

These figures are naturally only an approximation, but they show that even in a comparatively poor ground there exists more than an abundance of nourishment for the coconut tree, provided the soil itself is sufficiently porous and well watered.[3]

It seems very probable that in San Ramon at least, if not in most plantations along the seacoast, the nutritive material comes not from the soil in which the trees are actually growing but from an inexhaustible supply of water, laden with plant food, which is constantly seeping down from the higher ground toward the ocean. This underground water supply would account for the flourishing condition of trees in a sandy soil near the sea, even in times of drought, when individuals farther inland in higher, less permeable ground would be dying from want of water.

[3] See the paper by E. B. Copeland on the transpiration of the coconut and the amount of water taken up by an individual tree.

Fertilization and irrigation.—In the case of the less permeable soils, artificial irrigation during the dry season would seem to be of the utmost importance, and any addition to the fertility of the land, either in the form of manure or of a chemical fertilizer, would probably be repaid by an increased yield of fruit. For soils near the sea, under conditions such as exist at San Ramon, irrigation is of course unnecessary excepting in times of extreme drought, and fertilization would be of doubtful advantage, as the trees in such a location seem to be growing under the best conditions possible without any attention whatsoever. Fertilizing material in such localities would probably be leached out and carried into the sea before it could be of much value to the trees.

THE NUT AND ITS OIL PRODUCTION.

The analytical methods used in compiling the accompanying tables were as follows: The weights, in grams, of husk, nut minus husk, shell, and milk were determined directly. To avoid loss by evaporation the meat itself was not weighed but was assumed to be the difference between the weight of the whole nut (minus the husk) and the combined weights of shell and milk.

Copra.—The meat from each nut was allowed to dry in the air over night, so as to assume a fairly constant weight, and was then weighed directly; 25 grams were then cut into fine pieces and dried to constant weight at 100° C. for the determination of anhydrous copra, the latter being calculated back to per cent in the fresh meat. To approximate the amount of commercial copra obtainable, an addition of about 10 per cent should be made because of the water ordinarily contained in this product.

Oil.—The anhydrous copra prepared at San Ramon was sealed in glass bottles and shipped to Manila for analysis, the majority of the oil determinations being made by Mr. George F. Richmond, of this laboratory. Before this time much work had been done in devising a method for the rapid and accurate estimation of oil in copra. It was found to be almost impossible to make a complete extraction by the ordinary method of cutting fine pieces and extracting with ether in a Soxhlet cone. Even after the apparatus had been running for forty hours, a small increase in weight was obtained by extracting for eight hours more. Grinding with sand and then extracting with ether produced some improvement. Extraction with hot chloroform alone took out a little more oil, but it was necessary to continue the operation for at least sixteen hours. The method finally used was as follows:

A 2-gram sample was intimately ground with fine sand in a glass mortar, the mixture transferred to a Soxhlet cone, the mortar washed two or three times with fresh sand, and then finally wiped with fat-free cotton. The extraction with hot chloroform takes three hours.

The chloroform is then distilled and the remaining oil dried to constant weight at 100° C. Experiment demonstrated that practically all the oil was extracted in two hours. The chloroform extract made in this way proved to be entirely soluble in absolute ether. The sand used was prepared from ordinary sea sand by taking all which went through a 30-mesh and which was retained on a 100-mesh sieve, heating this product for some time to destroy organic matter and then afterwards extracting with chloroform.

Age in reference to quality of the nut.—One of the first and most important of the problems which presented itself was to determine the effect of the age and the relative maturity of the nut on the percentage of its various constituents; in other words, to find out the most favorable time for opening a nut to obtain the largest and best yield of copra and of oil. With this end in view, the following analyses were made of four series of ten nuts each:

Series I consisted of 10 nuts selected from a pile which had just been picked from the trees and which were ready to be used for making copra. These nuts were all fairly ripe, although the husks were still green in color and full of water.

Series II was made up of 10 nuts from the same pile as Series I, but all were very ripe. The husks were dry and of a dead-brown color.

Series III represents nuts which had been selected for seed and set out to sprout about three months before the time of analysis. They each contained a small embryo or "foot" and had green sprouts protruding to a height of about 6 inches. The husks had absorbed a large amount of water while lying on the ground.

Series IV was a rather abnormal lot of nuts which had been set out for seed similarly to those in Series III, but for some reason the individual ones had failed to sprout, although they had been standing for six months. The meat had become somewhat softened and in several cases it was discolored and possessed a bad odor. To a greater extent than any other this series shows what large variations may exist among nuts of the same age.

SERIES I.—*Ten nuts, fresh from trees but fairly ripe (all green husks).*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	2,702	1,160	42.9	1,542	57.1	200	10.8	725	26.8	45.2	54.8
2	2,725	1,265	46.4	1,460	53.6	330	12.1	590	21.7	43.9	56.1
3	3,039	1,510	49.7	1,529	50.3	395	13.0	639	21.0	54.8	45.2
4	3,182	1,547	48.6	1,635	51.4	340	10.7	585	18.4	32.8	67.2
5	2,830	1,300	45.9	1,530	54.1	299	10.6	606	21.4	44.5	55.5
6	2,316	1,106	47.8	1,210	52.2	239	10.3	541	23.4	46.1	53.9
7	2,872	1,157	40.3	1,715	59.7	338	11.8	652	22.7	43.9	56.1
8	2,930	1,350	46.1	1,580	53.9	345	11.8	580	19.8	48.5	51.5
9	2,100	925	44.0	1,175	56.0	260	12.4	505	24.1	53.2	46.8
10	3,787	1,915	50.6	1,872	49.4	395	10.4	717	18.9	51.7	48.3
Average	2,848	1,323	46.2	1,525	53.8	323	11.4	614	21.8	46.5	53.5

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	327	67.2	32.8	12.1	527	19.5	220	8.1	18.8	47.0	21.2	34.2	14.3
2	259	66.4	33.6	9.5	540	19.8	172	6.3	22.6	40.4	17.7	37.0	11.8
3	351	69.3	30.7	11.5	495	16.3	243	8.0	25.8	41.8	23.0	32.4	15.9
4	192	59.8	40.2	6.0	710	22.3	115	3.6	20.8	35.8	11.7	43.4	7.0
5	270	63.4	36.6	9.5	625	22.1	171	6.0	19.5	39.6	17.7	40.9	11.2
6	250	64.9	35.1	10.8	430	18.6	162	7.0	19.8	44.7	20.7	35.5	13.4
7	287	62.3	37.7	10.0	725	25.2	179	6.2	19.7	38.0	16.7	42.3	10.4
8	281	63.0	37.0	9.6	655	22.3	177	6.0	21.8	36.7	17.8	41.5	11.2
9	269	65.3	34.7	12.8	410	19.5	176	8.4	22.1	43.0	22.9	34.9	15.0
10	371	68.7	31.3	9.8	760	20.1	255	6.7	21.1	38.3	19.8	40.6	13.6
Average	286	65.0	35.0	10.2	588	20.6	187	6.6	21.2	40.5	18.9	38.3	12.4

SERIES II.—*Ten nuts, very ripe (dead-brown husks).*

[Selected from pile of several thousand.]

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	2,616	665	25.4	1,951	74.6	352	13.5	774	29.6	43.5	56.5
2	1,935	350	18.1	1,585	81.9	328	17.0	602	31.1	59.9	40.1
3	2,025	460	22.7	1,565	77.3	262	13.0	644	32.5	50.9	49.1
4	1,681	332	19.7	1,349	80.3	283	16.8	596	35.5	51.5	48.5
5	2,070	480	23.2	1,590	76.8	320	15.5	585	28.2	51.6	48.4
6	2,192	647	29.5	1,545	70.5	380	17.4	715	32.6	56.3	43.7
7	2,945	460	15.6	2,485	84.4	430	14.6	980	33.3	42.4	57.6
8	1,948	437	22.4	1,511	77.6	330	17.0	641	32.9	56.9	43.1
9	2,049	500	24.4	1,549	75.6	309	15.1	675	32.9	51.7	48.3
10	1,735	425	24.5	1,310	75.5	260	15.0	590	34.0	54.4	45.6
Average	2,120	476	22.6	1,644	77.5	326	15.5	680	32.3	52.0	48.0

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	337	54.0	46.0	12.9	825	31.5	182	7.0	18.0	39.7	17.3	42.3	9.3
2	360	66.4	33.6	18.6	655	33.8	239	12.3	20.7	38.0	22.7	41.3	15.1
3	328	61.7	38.3	16.2	659	31.8	202	10.0	16.7	41.2	21.0	42.1	12.9
4	307	62.2	37.8	18.3	470	28.0	191	11.4	21.0	44.2	22.8	34.8	14.2
5	302	59.6	40.4	14.6	685	33.1	180	8.7	20.1	36.8	19.0	43.1	11.3
6	402	58.9	41.1	18.3	450	20.5	237	10.8	24.6	46.3	26.0	29.1	15.3
7	415	58.1	41.9	14.1	[a]1,075	36.5	241	8.2	17.3	39.4	16.7	43.3	9.7
8	365	66.3	33.7	18.7	540	27.7	242	12.4	21.8	42.4	24.2	35.8	16.0
9	349	63.3	36.7	17.0	565	27.6	221	10.8	19.9	43.6	22.5	36.5	14.3
10	321	63.1	36.9	18.5	460	26.5	203	11.7	19.9	45.0	24.5	35.1	15.5
Average	349	61.4	38.6	16.7	638	29.7	214	10.3	20.0	41.7	21.7	38.3	13.4

[a] Milk very turbid.

SERIES III.—*Nuts stored three months, just beginning to sprout.*

No.	Total weight.	Embryo.	Husk.		Nut minus husk.		Shell.		Meat.			
			Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	2,935	15	1,313	44.7	1,622	55.3	326	11.1	711	24.2	57.2	42.8
2	2,133	25	1,060	49.7	1,073	50.3	232	10.9	553	25.9	50.7	49.3
3	1,966	15	729	37.1	1,237	62.9	275	14.0	557	28.3	55.7	44.3
4	1,666	10	565	33.9	1,101	66.1	242	14.5	509	30.6	52.8	47.2
5	2,791	20	1,653	59.2	1,138	40.8	232	8.3	561	20.1	49.9	50.1
6	2,537	5	1,395	55.0	1,142	45.0	285	11.2	505	19.9	52.8	47.2
7	2,664	50	973	36.5	1,691	63.5	299	11.2	752	28.2	49.9	50.1
8	3,993	5	2,731	68.4	1,262	31.6	281	7.0	536	13.4	51.5	48.5
9	5,062	15	3,115	61.5	1,947	38.5	398	7.9	849	16.8	40.3	59.7
10	2,300	10	1,160	50.4	1,140	49.6	273	11.9	540	23.5	51.7	48.3
Average	2,805	17	1,469	49.6	1,335	50.4	284	10.8	607	23.1	51.3	48.7

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	407	62.4	37.6	13.9	570	19.4	254	8.7	20.1	43.8	25.1	35.2	15.7
2	280	59.5	40.5	13.1	263	12.3	167	7.8	21.6	51.5	26.1	24.5	15.5
3	311	63.8	36.2	15.8	390	19.8	199	10.1	22.2	44.9	25.2	31.5	16.0
4	269	63.6	36.4	16.1	340	20.4	171	10.3	22.0	46.2	24.4	30.9	15.5
5	280	65.1	34.9	10.0	325	11.6	182	6.5	20.4	49.3	24.6	28.6	16.0
6	266	58.7	41.3	10.5	347	13.7	156	6.2	25.0	44.2	23.3	30.4	13.7
7	375	60.0	40.0	14.1	590	22.2	225	8.4	17.7	44.5	22.2	34.9	13.3
8	276	60.6	39.4	6.9	440	11.0	167	4.2	22.2	42.5	21.9	34.9	13.3
9	342	62.2	37.8	6.8	685	13.5	212	4.2	20.4	43.6	17.6	35.2	10.9
10	279	62.1	37.9	12.1	317	13.8	173	7.5	24.0	47.4	24.5	27.8	15.2
Average	309	61.8	38.2	11.9	427	15.8	191	7.4	21.6	45.8	23.5	31.4	14.5

SERIES IV.—*Nuts stored six months which had not sprouted.*

[Most nuts of this age have sprouts 20 to 30 centimeters long.]

No.	Total weight.	Embryo.	Husk. Weight.	Husk. Per cent.	Nut minus husk. Weight.	Nut minus husk. Per cent.	Shell. Weight.	Shell. Per cent.	Meat. Weight.	Meat. Per cent.	Meat. Per cent copra.	Meat. Per cent water.
		Grams.										
1	2,908	6	1,272	43.7	1,636	56.3	367	12.6	683	23.5	51.3	48.7
2	2,541	-------	1,382	54.4	1,159	45.6	197	7.8	492	19.3	33.0	67.0
3	3,419	-------	1,743	51.0	1,676	49.0	360	10.5	666	19.5	44.1	55.9
4	3,154	-------	1,462	46.3	1,692	53.7	277	8.8	800	25.4	51.3	48.7
5	2,023	5	1,123	55.5	900	44.5	252	12.5	500	24.7	54.7	45.3
6	2,276	-------	1,228	54.0	1,048	46.0	160	7.0	478	21.0	33.2	66.8
7	3,116	-------	1,939	62.2	1,176	37.8	260	8.4	536	17.2	37.3	62.7
8	2,403	-------	1,443	60.1	960	39.9	180	7.5	453	18.8	29.3	70.7
9	3,238	-------	1,800	55.6	1,438	44.4	262	8.1	696	21.5	34.9	65.1
10	3,585	-------	2,225	62.1	1,360	37.9	272	7.6	638	17.8	38.2	61.8
Average	2,866	-------	1,562	54.5	1,305	45.5	259	9.1	594	20.9	40.7	59.3

No.	Copra (anhydrous). Weight.	Copra (anhydrous). Per cent oil.	Copra (anhydrous). Per cent pulp.	Copra (anhydrous). Per cent copra in nut.	Milk. Weight.	Milk. Per cent.	Oil. Weight.	Oil. Per cent.	Calculated to per cent in nut free from husk. Shell.	Meat.	Copra.	Milk.	Oil.
1	350	61.4	38.6	12.1	580	20.1	216	7.4	22.5	41.6	21.4	35.5	13.1
2	170	67.7	32.3	6.7	470	18.5	115	4.5	17.0	42.5	14.7	40.5	9.9
3	294	69.0	31.0	8.6	650	19.0	203	5.9	21.5	39.7	17.5	38.8	12.1
4	410	68.4	31.6	13.0	615	19.5	281	9.9	16.4	47.3	24.2	36.3	16.6
5	274	74.4	25.6	13.5	143	7.1	204	10.1	28.0	55.6	38.3	15.9	22.7
6	136	56.3	43.7	6.0	410	18.0	77	3.4	15.3	45.6	13.0	39.1	7.3
7	200	66.2	33.8	6.4	380	12.2	132	4.2	22.1	45.6	17.0	32.3	11.3
8	132	74.1	25.9	5.5	327	13.6	98	4.1	18.7	47.2	13.8	34.1	10.2
9	242	63.4	36.6	7.5	480	14.8	153	4.7	18.2	48.4	16.8	33.4	10.7
10	244	58.5	41.5	6.8	450	12.5	143	4.0	20.0	46.9	17.9	33.1	10.5
Average	245	65.9	34.1	8.6	451	15.5	162	5.8	20.0	46.0	19.5	34.0	12.4

The variation among individual nuts in the foregoing analyses was rather greater than had been expected, and it is doubtful if even an average of ten nuts gives more than an approximation of their true value at a given age.

However, considering the average percentages as calculated to the nut free from husk, there appears a gradual increase in the proportion of meat, copra, and oil from Series I to Series III, with a corresponding decrease in the percentage of milk, indicating that the meat is becoming firmer, is losing some water and gaining oil, as the nut increases in age. In Series IV, those nuts which had been kept for six months, the meat remains practically the same in amount, but there is a marked drop in the proportion of copra and oil, probably due to decomposition or other changes which are beginning to take place in the meat. However, No. 5 of this series, a nut in which decomposition had already set in, shows an abnormally high percentage of both copra and oil, a fact which is very hard to account for, although it is possible that this individual may have been still higher in these substances before decomposition began. In both Series I and IV the percentage of oil in the anhydrous copra is considerably higher than it is in II and III, though this is more than counterbalanced by a much lower proportion of copra in the meat. Both in very fresh and in overripe nuts there is a considerable deficiency in oil, but the principal loss is in the amount of copra to be obtained, this result being due to a higher percentage of water as compared with solid matter in the meat. In all these nuts it will be noticed that the proportion of shell to the whole nut varies but little.

Analyses of nuts from the same trees but of varying degrees of ripeness.—In order as much as possible to eliminate the variations in the individual nuts, and to discover if those taken from the same tree would not show greater uniformity in their composition, fifty nuts from one tree near San Ramon were procured for analysis.

Ten of the least ripe among these were analyzed as shown in Series V. All of the individuals of this series were well developed externally, but were full of milk, and not yet sufficiently mature to be picked for making copra.

The ten ripest nuts of the lot were next selected (Series VII). Their husks were of a dead-brown color and thoroughly dry.

The remaining thirty were in a condition which might be termed "fairly ripe"—that is, they were of the kind ordinarily used for making copra. Nine of these were analyzed at once (Series VI), and the remainder shipped to Manila for storage and future analysis. In Series V, VI, and VII "total solids" in the milk were determined in addition to the regular analysis.

SERIES V.—*Ten nuts not fully ripe, fresh from tree.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.				Copra (anhydrous).	
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.	Weight.	Per cent oil.
1	4,227	2,995	70.9	1,232	29.1	232	5.5	410	9.7	33.2	66.8	136	------
2	4,018	2,770	69.0	1,248	31.0	240	6.0	428	10.6	34.3	65.7	147	66.9
3	4,012	2,882	71.9	1,130	28.1	220	5.5	378	9.4	30.0	70.0	114	63.9
4	4,535	3,380	74.5	1,155	25.5	219	4.8	394	8.7	27.7	72.3	109	64.5
5	3,737	2,655	71.0	1,082	29.0	205	5.5	362	9.7	26.0	74.0	94	56.0
6	3,931	2,787	70.9	1,144	29.1	214	5.5	418	10.6	33.2	66.8	139	62.0
7	3,919	2,850	72.7	1,069	27.3	212	5.4	347	8.9	29.8	70.2	103	64.6
8	3,967	2,700	68.1	1,267	31.9	244	6.1	419	10.6	37.2	62.8	156	66.9
9	4,046	2,806	69.4	1,240	30.6	239	5.9	450	11.1	37.5	62.5	152	65.8
10	3,187	1,965	61.7	1,222	38.3	240	7.5	445	14.0	48.2	51.8	214	69.9
Average	3,958	2,779	70.0	1,179	30.0	227	5.8	405	10.3	33.7	66.3	136	64.5

No.	Copra (anhydrous).		Milk.				Oil.		Calculated to per cent in nut free from husk.				
	Per cent plup.	Per cent copra in nut.	Per cent solids.	Per cent water.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	------	3.2	6.0	94.0	590	13.9	------	------	18.8	33.3	11.0	47.9	------
2	33.1	3.7	5.9	94.1	580	14.4	98	2.4	19.2	34.3	11.8	46.5	7.9
3	36.1	2.8	6.5	93.5	532	13.2	73	1.8	19.5	33.4	10.1	47.1	6.4
4	35.5	2.4	6.5	93.5	542	12.0	70	1.6	19.0	34.1	9.4	46.9	6.1
5	44.0	2.5	6.7	93.3	515	13.8	53	1.4	18.9	33.5	8.7	47.6	4.9
6	38.0	3.5	6.0	94.0	512	13.0	86	2.2	18.7	36.5	12.2	44.8	7.5
7	35.4	2.6	6.6	94.4	510	13.0	67	1.7	19.8	32.6	9.6	47.7	6.2
8	33.1	3.9	6.7	93.3	604	15.2	104	2.6	19.3	33.1	12.3	47.6	8.1
9	34.2	3.8	6.0	94.0	551	13.6	100	2.5	19.3	36.3	12.3	44.4	8.1
10	30.1	6.7	5.6	94.4	537	16.8	150	4.7	19.6	36.4	17.5	44.0	12.2
Average	35.5	3.5	6.3	93.7	547	13.9	89	2.3	19.2	34.4	11.5	46.4	7.5

SERIES VI.—*Nine nuts from same tree as Series V, but fairly ripe.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.				Copra (anhydrous).	
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.	Weight.	Per cent oil.
1[a]	1,644	602	36.6	1,042	63.4	207	12.6	460	28.0	50.7	49.3	233	63.8
2[a]	1,670	650	38.9	1,020	61.1	201	12.0	455	27.3	54.6	45.4	218	62.7
3[b]	2,300	1,115	48.4	1,185	51.6	229	10.0	506	22.0	51.8	48.2	262	64.3
4[b]	2,164	1,075	49.7	1,089	50.3	217	10.0	465	21.4	50.5	49.5	235	64.1
5[c]	2,519	1,294	51.4	1,225	48.6	231	9.1	501	19.9	49.5	50.5	248	64.1
6[c]	1,948	992	50.9	956	49.1	186	9.6	400	20.5	53.6	46.4	215	65.8
7[c]	3,467	2,262	65.2	1,205	34.8	232	6.7	473	13.7	45.5	54.5	215	66.9
8[c]	2,512	1,440	57.3	1,072	42.7	197	7.9	450	17.9	50.4	49.6	227	64.9
9[c]	3,230	1,985	61.4	1,245	38.6	229	7.1	471	14.6	44.3	55.7	208	65.7
Average	2,384	1,268	51.1	1,116	48.9	214	9.4	465	20.6	50.1	49.9	232	64.7

No.	Copra (anhydrous).		Milk.				Oil.		Calculated to per cent in nut free from husk.				
	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Per cent solids.	Per cent water.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	36.2	14.2	375	22.8	4.4	[d]95.6	149	9.0	19.9	44.1	22.4	36.0	14.3
2	37.3	14.9	364	21.8	4.1	[d]95.9	156	9.3	19.7	41.6	21.3	35.7	15.3
3	35.7	11.4	450	19.6	5.0	95.0	169	7.3	19.3	42.7	22.1	38.0	14.2
4	35.9	10.8	407	18.8	4.9	95.1	151	7.0	19.9	42.7	21.5	37.4	13.8
5	35.9	9.8	493	19.6	5.7	94.3	159	6.3	18.9	40.9	20.3	40.2	13.0
6	34.2	11.0	370	19.0	5.2	94.8	142	7.3	19.5	41.8	22.5	38.7	14.8
7	33.1	6.2	500	14.4	5.6	94.4	144	4.1	19.3	39.2	17.8	41.5	11.9
8	35.1	9.0	425	16.9	5.8	94.2	147	5.9	18.4	42.0	21.2	39.6	13.7
9	34.3	6.4	545	16.9	6.0	94.0	137	4.2	18.4	37.8	16.7	43.8	11.0
Average	35.3	10.4	437	18.9	5.2	94.8	150	6.7	19.3	41.7	21.0	39.0	13.6

[a] "Dead ripe." [b] "Ripe." [c] "Fairly ripe." [d] Oil separated.

SERIES VII.—*Nuts from same tree as Series V, but dead ripe.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.				Copra (anhydrous).	
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.	Weight.	Per cent oil.
1	1,624	545	33.6	1,079	66.4	217	13.4	462	28.4	51.9	48.1	240	63.9
2	1,493	486	32.6	1,007	67.4	202	13.5	450	30.1	55.1	44.9	248	66.0
3	1,427	547	38.3	880	61.7	185	13.0	415	29.1	58.6	41.4	243	66.6
4	1,495	445	29.8	1,050	70.2	187	12.5	438	29.3	45.3	54.7	198	65.3
5	1,568	528	33.7	1,040	66.3	202	12.9	441	28.1	53.5	46.5	236	64.2
6	1,437	472	32.8	965	67.2	198	13.8	437	30.4	56.7	43.3	248	67.1
7	1,716	631	36.8	1,085	63.2	202	11.8	476	27.7	51.8	48.2	246	67.5
8	1,564	489	31.3	1,075	68.7	206	13.1	483	30.9	53.3	46.7	261	65.0
9	1,452	450	31.0	1,002	69.0	188	13.0	436	30.0	53.5	46.5	233	65.6
10	1,806	612	33.9	1,194	66.1	219	12.1	496	27.5	53.6	46.4	266	68.3
Average	1,558	520	33.4	1,038	66.6	201	12.9	453	29.1	53.3	46.7	242	66.0

No.	Copra (anhydrous).		Milk.				Oil.		Calculated to per cent in nut free from husk.				
	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Per cent solids.	Per cent water.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	36.1	14.8	400	24.6	4.5	95.5	153	9.4	20.1	42.8	22.2	37.1	14.2
2	34.0	16.6	355	23.8	4.3	95.7	164	11.0	20.0	44.7	24.7	35.3	16.3
3	33.4	17.1	280	19.6	5.0	95.0	162	11.3	21.0	47.2	27.6	31.8	18.4
4	34.7	13.3	425	28.4	4.3	95.7	129	8.6	17.8	41.7	18.9	40.5	12.3
5	35.8	15.1	397	25.3	4.1	95.9	152	9.7	19.4	42.4	22.7	38.2	14.6
6	32.9	17.2	330	23.0	4.5	95.5	166	11.6	20.5	45.3	25.7	34.2	17.3
7	32.5	14.4	407	23.7	4.0	96.0	166	9.7	18.6	43.9	22.7	37.5	15.3
8	35.0	16.7	386	24.7	4.3	95.7	170	10.9	19.2	44.9	24.3	35.9	15.8
9	34.4	16.1	378	26.0	4.6	95.4	153	10.5	18.8	43.5	23.3	37.7	15.3
10	31.7	14.7	479	26.5	4.3	95.7	182	10.1	18.3	41.6	22.3	40.1	15.2
Average	34.0	15.6	384	24.6	4.4	95.6	160	10.3	19.4	43.8	23.4	36.8	15.5

While there is still some individual variation among nuts from the same tree, these last analyses very conclusively show the change which is taking place as the fruit becomes riper. The average percentages of copra and oil, for example, in the nut free from husk in the green fruit, are only 11.5 and 7.5, respectively, but they rise to 21 and 13.6 in the "fairly ripe" nuts, and assume a maximum of 23.4 and 15.5 in the case of the series which had been allowed completely to ripen while still on the tree. This gain is partially due to an increase in the percentage of meat, which runs 34.4, 41.7, and 43.6 in Series V, VI, and VII, respectively, at the expense of milk, which falls from 46.4 to 39 and finally to 36.8, but it is also largely accounted for by the increase of solid matter and loss of water in the former. The percentage of anhydrous copra in

the meat of the green fruit is 33.7; it rises to 50.1 in that of the "fairly ripe" nuts and increases to 53.3 in those marked "dead ripe." The "fairly ripe" nuts which had been sent to Manila showed 51.4 per cent of anhydrous copra in the meat after standing during one month, and, after two, 53.9 per cent, this last figure being very nearly the same as that obtained from the "dead-ripe" nuts taken directly from the tree. The amount of oil obtainable from this copra also seems slightly to increase with age, running 64.5, 64.7, and 66 in the three series (V, VI, and VII), and in those nuts which had stood for one and two months it was found to be 67.09 and 67.11, respectively. However, it is also quite possible that these changes of oil content in the copra in greater part are due to individual variation in the nuts themselves.

Another interesting fact brought out by these analyses is the gradual decrease of the amount of the total solids in the milk as a nut grows riper. In green nuts this quantity averaged 6.3 per cent and the milk has a sweet, pleasant taste and is saturated with a gas which I have proven to be carbon dioxide. The occurrence of an alcoholic fermentation in the center of a sound, growing fruit, with absolutely no access of air to the milk inside, is practically impossible, and, besides, analytical tests have proven the absence of alcohol in the fresh milk, so that probably the carbon dioxide is a by-product of a process, possibly due to enzymes, which is constantly changing sugar and water into fat and cellulose. The milk from the nuts called "fairly ripe" was not so pleasant to the taste, contained very little, if any, carbon dioxide, and had decreased in total solids to 5.2 per cent; while the "dead-ripe" samples produced a milk which was rather insipid, which contained no gas, and which in most cases had a few drops of clear oil floating on the surface; the total solids in the latter had been further reduced to 4.4 per cent.

Changes taking place during the ripening of a coconut.—From the foregoing data, and from observations made on very young nuts, the following are probably the changes which a young coconut undergoes before it reaches maturity:

When the young fruit first appears it consists of a white, astringent tasting, semifibrous mass, which afterwards is destined to form the husk; and of a thin, green outer skin. The nut gradually increases in size, with very little change in composition, until it has grown to be about 3 inches in diameter. It then has a comparatively small, hollow space in the center which is completely filled with a watery fluid of an astringent, slightly acid taste, and which is much like the juice from a green husk. As this period begins, a rudimentary shell is formed around the inner surface of the nut; at first this is very thin and soft, but slowly it becomes thicker and harder. Not until the nut has reached its maximum size, with its shell completed, is there any indication of meat or of oily material. When the shell has been formed the milk changes in character,

it becomes rather sweet, and a slimy, gelatinous mass, having a sweetish taste and containing comparatively little oil begins to deposit on the inside of the former. At first this forms chiefly on the lower half of the nut, but finally it covers the whole inner surface. This pulpy mass soon grows thicker and denser, it increases in oil content at the expense of sugar in the milk, until it assumes the well-known characteristics of ordinary coconut meat. During this last stage the evolution of carbon dioxide which previously was mentioned occurs. Even in ripe nuts, after they have been picked from the tree, there seems to be a slight continuation of the hardening process in the meat, covering a period of from two to three months, or until the sprout makes its appearance. Then other changes occur, the reverse of those which had taken place previously; the nourishment concentrated and stored up as fat is now transformed into sugars and other bodies capable of being directly assimilated by the young plant. As this process goes on the embryo or "foot" gradually increases in size until it occupies the whole space inside the nut and makes use of all the nourishment contained therein for the growth of the young tree.

Therefore, for the largest yield of copra and oil, only thoroughly ripe nuts (the husks of which have begun to turn brown) should be used, and it is often advisable to allow the latter to stand in a dry place for a few weeks before they are opened. The greatest care should be taken to avoid using green nuts, as it is shown by the tables given above that a loss of almost 50 per cent may thus result.

On the other hand, coconuts should not be stored too long, for in about three months the embryo begins to grow, and, even before that time, those nuts which may have been cracked or bruised in gathering, have a tendency to become rancid.

Analysis of nuts of different color.—In a certain portion of San Ramon farm there exist, growing side by side in the same kind of soil, two apparently different varieties of coconut trees, one of which uniformly produces nuts of a golden-yellow color, while the other bears a light-green fruit. Both varieties eventually turn brown at maturity. Analyses of these nuts are given in the accompanying tables, Series VIII being ten ripe nuts from a tree which bears a green fruit, while Series IX is made up of nuts from a tree about 50 feet away whose product is yellow until it becomes "dead ripe."

SERIES VIII.—*Ten thoroughly ripe nuts from one tree.*

[The nuts on this tree all have a green husk until they become "dead ripe," when they change to a dull brown.]

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	1,490	585	39.3	905	60.7	204	13.7	397	26.6	44.6	55.4
2	2,160	640	29.6	1,520	70.4	275	12.4	663	30.7	52.6	47.4
3	1,632	657	40.3	975	59.7	227	13.9	428	26.2	46.3	53.7
4	1,482	437	29.5	1,045	70.5	235	15.9	438	29.5	44.4	55.6
5	1,862	665	35.7	1,197	64.3	265	14.2	482	25.9	44.4	55.7
6	1,517	395	26.0	1,122	74.0	255	16.8	467	30.8	53.5	46.5
7	1,702	567	33.3	1,135	66.7	260	15.3	498	29.2	46.8	53.2
8	1,623	520	32.0	1,103	68.0	265	16.4	476	29.3	51.3	48.6
9	1,900	700	36.8	1,200	63.2	270	14.2	505	26.6	44.6	55.3
10	1,673	475	28.4	1,198	71.6	210	12.6	521	31.1	57.0	43.0
Average	1,704	564	33.1	1,140	66.9	247	14.6	488	28.6	48.5	51.5

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	177	64.2	35.8	11.9	304	20.4	114	7.6	22.5	43.9	19.6	33.6	12.6
2	349	62.5	37.5	16.1	582	26.9	218	10.1	18.1	43.6	23.0	38.3	14.3
3	198	62.7	37.3	12.1	320	19.6	124	7.6	23.3	43.9	16.1	32.8	12.7
4	195	62.6	37.4	13.1	372	25.1	122	8.2	22.5	41.9	18.7	35.6	11.7
5	214	60.8	39.2	11.5	450	24.2	130	7.0	22.1	40.3	17.9	37.6	10.9
6	250	65.0	35.0	16.5	390	25.7	163	10.7	22.7	41.6	22.3	34.8	14.5
7	233	67.0	33.0	13.7	377	22.2	170	9.2	22.9	43.9	20.5	33.2	13.8
8	242	64.3	35.7	14.9	362	22.3	156	9.6	24.0	43.2	22.0	32.8	14.1
9	225	65.9	34.1	11.9	425	22.4	148	7.8	22.5	42.1	18.8	35.4	12.4
10	297	64.6	35.4	17.7	467	27.9	192	11.5	17.5	43.5	21.8	39.0	16.0
Average	238	64.0	36.0	13.9	405	23.7	154	8.9	21.8	42.8	20.4	35.3	13.3

SERIES IX.—*Ten thoroughly ripe nuts from one tree.*

[These nuts have a golden-yellow color until dead ripe, when they look like those of Series VIII.]

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	1,613	428	26.5	1,185	73.5	230	14.3	495	30.7	47.1	52.9
2	1,960	520	26.7	1,440	73.3	256	13.0	589	30.0	53.6	46.4
3	1,657	375	22.6	1,282	77.3	240	14.5	547	33.0	53.4	46.6
4	1,608	353	22.0	1,255	78.0	235	14.5	545	33.9	52.7	49.3
5	1,653	335	20.3	1,318	79.7	245	14.8	568	34.4	53.1	46.9
6	1,577	560	35.5	1,017	64.5	205	13.0	432	27.4	49.6	51.3
7	1,780	510	28.7	1,270	71.3	252	14.2	533	29.9	53.6	46.4
8	1,650	380	23.0	1,270	77.0	247	15.0	538	32.6	51.2	48.8
9	1,597	497	31.1	1,100	68.9	225	14.2	495	30.9	43.4	56.6
10	1,926	486	25.2	1,440	74.8	257	13.4	591	30.7	51.2	48.8
Average	1,702	444	26.2	1,258	73.8	239	14.1	533	31.3	50.9	49.1

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	233	Copra destroyed on route; assume same per cent as in Series VIII: 64.		14.5	460	28.5	149	9.2	19.4	41.8	19.6	38.8	12.6
2	315			16.1	595	30.3	202	10.3	17.8	40.9	21.9	41.3	14.0
3	292			17.6	495	29.8	187	11.3	18.7	42.7	22.8	38.6	14.6
4	287			17.8	475	29.6	184	11.4	18.7	43.4	22.9	37.9	14.6
5	301			18.2	505	30.5	193	11.7	18.6	43.1	22.8	38.3	14.6
6	214			13.6	380	24.1	137	8.7	20.1	42.5	21.1	37.4	13.5
7	285			16.0	485	27.2	182	10.2	19.9	42.0	22.4	38.2	14.4
8	276			16.7	485	29.4	177	10.7	19.5	42.9	21.7	38.2	13.9
9	215			13.5	380	23.8	138	8.6	20.5	45.0	19.5	34.5	12.5
10	302			15.7	592	30.7	193	10.0	17.9	41.0	21.0	41.1	13.4
Average	272			16.0	485	28.4	174	10.2	19.1	42.5	21.6	38.4	13.8

Very little difference can be observed between these two varieties; the average weight is almost exactly the same; the percentage of husk and shell is somewhat lower in the yellow nuts, but this advantage to a large extent is counterbalanced by their percentage in milk, so that the amount of meat in the two remains practically the same. The yellow nuts average 272 grams of anhydrous copra against 238 grams in the green ones, which is quite decidedly in favor of the former.

Unfortunately, the copra from Series IX was spoiled in transit to Manila. Calculations on the oil contents of this series were therefore based on the assumption that this copra would have contained 64 per cent oil—that is, the same percentage as that found in Series VIII. Figuring the yield of oil on this basis, we have an average of 174 grams for the yellow nuts against 154 for the green ones. However, it will be noticed that these tables show a difference of over 100 grams in each series between the maximum and minimum weight of oil, therefore if another series of analyses of nuts from these two trees were to be made possibly the slight advantage in favor of the yellow nuts might be reversed. At any rate it may be concluded that the color of a nut has very little, if any, influence on its composition.

Nuts from different localities.—In order to test the truth of the statement that coconuts produced by trees growing along the seashore are of a quality superior to those taken from farther inland, ten nuts were selected at random from a large pile gathered near the sea and analyzed as shown in the accompanying Series X, while a like number was secured from a similar one containing the product of trees growing some 1,800 feet inland (Series XI).

SERIES X.—*Ten nuts from a pile of 1,000 taken from trees near the sea.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1 [a]	3,125	1,420	45.4	1,705	54.6	310	9.9	745	23.8	54.3	45.7
2 [b]	2,165	633	29.2	1,532	70.8	285	13.2	627	29.0	59.1	40.9
3 [c]	2,520	1,210	48.0	1,310	52.0	301	12.0	549	21.8	54.8	45.2
4 [b]	3,492	1,560	44.7	1,932	55.3	425	12.1	775	22.2	45.0	55.0
5 [a]	2,292	992	43.3	1,300	56.7	300	13.1	608	26.5	57.8	42.2
6 [d]	3,215	1,355	42.1	1,860	57.9	359	11.2	701	21.8	49.8	50.2
7 [d]	2,785	1,405	50.4	1,380	49.6	291	10.5	594	21.3	42.2	57.8
8 [b]	2,512	792	31.5	1,720	68.5	340	13.5	738	29.4	57.3	42.7
9 [e]	3,240	1,320	40.8	1,920	59.2	380	11.7	780	24.1	51.5	48.5
10 [d]	2,765	1,170	42.3	1,595	57.7	262	9.5	683	24.7	49.7	50.3
Average	2,811	1,186	41.8	1,625	58.2	325	11.7	680	24.4	52.2	47.8

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	404	65.3	34.7	12.9	650	20.9	264	8.4	18.2	43.7	23.7	38.1	15.5
2	370	67.3	32.7	17.1	620	28.6	249	11.5	18.6	40.9	24.2	40.5	16.3
3	306	65.7	34.3	12.1	460	18.2	201	8.0	23.0	41.9	23.4	35.1	15.4
4	349	64.0	36.0	10.0	732	21.0	224	6.4	22.0	40.1	18.1	37.9	11.6
5	349	69.8	30.2	15.2	392	17.1	244	10.1	23.1	46.8	26.8	30.1	18.7
6	349	------	------	10.9	800	24.9	------	------	19.3	37.7	18.8	43.0	------
7	251	61.6	38.4	9.0	495	17.8	155	5.6	21.1	43.0	18.2	35.9	11.2
8	423	63.6	36.4	16.8	642	25.6	269	10.7	19.8	42.9	24.6	37.3	15.6
9	402	62.8	37.2	12.4	760	23.4	253	9.5	19.8	40.6	20.9	39.6	13.2
10	339	------	------	12.3	650	23.5	------	------	16.4	42.8	21.3	40.8	------
Average	354	65.0	35.0	12.9	620	22.1	232	8.8	20.1	42.1	22.0	37.8	14.7

[a] Yellow-green. [b] Brown. [c] Yellow. [d] Green. [e] Brown-yellow.

SERIES XI.—*Ten nuts from a pile of 1,000 taken from trees inland about 1,800 feet.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1[a]	4,114	1,612	39.2	2,502	60.8	540	13.1	857	20.8	45.3	54.7
2[b]	2,500	865	34.6	1,635	65.4	352	14.1	726	29.0	50.9	49.1
3[b]	2,512	652	26.0	1,860	74.0	352	14.0	746	29.7	57.0	43.0
4[b]	2,763	863	31.2	1,900	68.8	337	12.2	766	27.7	45.4	54.6
5[b]	2,745	815	29.7	1,930	70.3	343	12.5	752	27.4	51.2	48.8
6[c]	4,102	1,592	38.8	2,510	61.2	452	11.0	911	22.2	45.5	54.5
7[b]	2,485	525	21.1	1,960	78.9	345	13.9	820	33.0	49.3	50.7
8[b]	1,423	425	29.9	998	70.1	235	16.5	473	33.2	59.3	40.7
9[a]	2,675	1,000	37.4	1,675	62.6	342	12.8	603	22.5	37.3	62.7
10[d]	3,620	1,170	32.3	2,450	67.7	439	12.1	936	25.9	49.3	50.7
Average	2,894	952	32.0	1,942	68.0	374	13.2	759	27.2	49.1	50.9

No.	Copra (anhydrous).				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent oil.	Per cent pulp.	Per cent copra in nut.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	388	57.7	42.3	9.4	1,105	26.9	224	5.4	21.6	34.2	15.5	44.2	9.0
2	369	59.8	40.2	14.8	557	22.3	221	8.8	21.5	44.4	22.6	34.1	13.5
3	425	65.1	34.9	16.9	762	30.3	277	11.0	18.9	40.1	22.8	41.0	14.9
4	348	59.3	40.7	12.6	797	28.9	206	7.5	17.7	40.3	18.3	42.0	10.9
5	385	63.7	36.3	14.0	835	30.4	245	8.9	17.8	38.9	20.0	43.3	12.7
6	415	62.0	38.0	10.1	1,147	28.0	257	6.3	18.0	36.3	16.5	45.7	10.3
7	404	58.8	41.2	16.3	795	32.0	238	9.6	17.6	41.8	20.6	40.6	12.1
8	280	61.4	38.6	19.7	290	20.4	172	12.1	23.5	47.4	28.1	29.1	17.2
9	225	63.5	36.5	8.4	730	27.3	143	5.3	20.4	36.0	13.4	43.6	8.5
10	461	67.8	32.2	12.7	1,075	29.7	313	8.6	17.9	38.2	18.8	43.9	10.6
Average	370	61.9	38.1	13.5	809	27.6	230	8.4	19.5	39.8	19.7	40.7	12.0

[a] Green. [b] Brown. [c] Yellow-green. [d] Yellow.

In selecting nuts for the two preceding series of analyses no attempt was made to secure uniformity as to size and age. On the contrary, they were picked out with a view of obtaining fairly representative samples of the largest and of the smallest, as well as of the most and of the least mature in each pile, so that they would vary through a wide range of color and weight. On comparing the two lots it will be seen that the results agree very closely. Series XI averages a little higher in the total yield of copra, but the oil content of this copra is somewhat lower than in Series X, so that they yield almost exactly the same quantity of oil per nut. The proportion of husk taken from the seashore nuts (41.8) is much larger than it is from those gathered from the interior (32), but

this is compensated for by the fact that the percentage of milk in the nut, free from husk, and of water in the fresh meat is considerably lower in the former than in the latter. Therefore it appears to be very evident that the superiority of trees growing near the sea is solely due to the quantity and not to the quality of nuts they produce.

Analyses of large numbers of nuts.—As a check on these last results, secured on a small scale, it was decided to determine the actual weight of the various products of the coconut under the conditions ordinarily obtaining in the manufacture of commercial copra, and, with this end in view, 1,000 nuts were procured from trees growing near the seashore and the same number from those standing in the interior. After lying for one month the nuts were put through the regular process for making copra which has previously been described. The weight in pounds of the whole nuts, husks, meat and shells, dried shells, and copra was determined directly on an ordinary Fairbanks scale, the meat and milk being obtained by difference. Five hundred nuts from each lot were sun dried and 500 grill dried and the resulting weight of copra multiplied by two to give the yield of 1,000 nuts by each method. For the determination of moisture and oil in this copra, twenty samples were taken from each lot, cut into small pieces, and quartered down to about 100 grams. The moisture was determined at once, after which the copra was sealed and sent to Manila to secure the determination of the oil content. Both moisture and oil were determined in triplicate.

SERIES XII.

Portion determined.	Seashore nuts.		Inland nuts.	
	Weight in kilos.	Per cent.	Weight in kilos.	Per cent.
Weight of 1,000	2,363	100.0	2,286	100.0
Husks	897	38.0	703	30.8
Nuts minus husks	1,466	62.0	1,582	69.2
Meat and shell	929		979	
Milk	537	22.7	603	26.4
Shell (dry)	282	11.9	291	12.7
Meat	647	27.4	688	30.1

Portion determined.	Seashore nuts.				Inland nuts.			
	Sun dried.		Grill dried.		Sun dried.		Grill dried.	
	Weight in kilos.	Per cent.	Weight in kilos.	Per cent.	Weight in kilos.	Per cent.	Weight in kilos.	Per cent.
Copra	302.1	12.8	330.2	14.0	322.9	14.1	333.0	14.6
Oil	182.2	7.7	198.9	8.4	191.1	8.4	189.8	8.3
Moisture in copra		9.2		8.6		9.8		10.1
Oil in copra		60.3		60.2		59.2		57.0

This work, performed as it was on a large scale, agrees rather more closely with the results obtained from the series of ten nuts each than was to be expected. Here, again, it may be observed that the proportion of husk from the seashore nuts is considerably higher than it is from those from the interior, while the total amount of water is correspondingly less, so that nuts from the two localities yield practically the same amount of copra and oil.

While weighing out 1,000 nuts from the seashore trees it was found that 55 of them, or 5.5 per cent, were in such a bad condition as to be unfit for making copra, and fresh nuts had to be substituted. Out of the same number from the interior only 15 were spoiled. The cause of this difference is probably found in the fact that the nuts from trees near the sea fall upon harder ground and are therefore more apt to become bruised and injured, and it is very possible that the inferior yield of sun-dried as compared with kiln-dried copra, in the case of the seashore nuts, is due to this. Given perfectly sound coconuts, the two methods of drying should produce equal amounts of copra, but a green nut, or one which has begun to decay, would undoubtedly be more subject to the attacks of mold, bacteria, and insects during the comparatively long alternate heating and cooling incident to the sun-drying process than if it were dried quickly at a higher temperature.

The figures obtained in this last series on a commercial basis establish, even more firmly than do the results of analyses alone, the fact that there is practically no difference in quality between the nuts gathered along the seashore and those from farther inland. They should also be of some value as representing the average yield in copra and oil from nuts produced in the southern parts of the Islands.

NUTS FROM DAVAO.

The following analyses were made of ripe coconuts, collected near Davao, about 1 mile inland from the sea. In this region two varieties of trees have been noticed, one producing large nuts rather pointed in shape, the other bearing a smaller, rounder fruit.

Series XIII consists of ten of the small nuts, Series XIV of the large variety. On examining these figures it will be noticed that Series XIII shows very much the same proportion of its various constituents, as well as the total of oil, as the average lot of ripe nuts from San Ramon.

Series XIV excels in total weight of oil simply because it is made up of larger nuts. The percentage of oil in the nut, free from husk, is the same in both series. The nuts in these two series were fairly uniform in composition, with the exception of No. 7 in Series XIV, which had a total weight of only 92 grams of oil, less than one-half of the average amount.

SERIES XIII.—*Davao nuts, small.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.			
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.
1	2,016	480	23.8	1,536	76.2	296	14.7	672	33.3	48.2	51.8
2	2,220	548	24.7	1,672	75.3	347	15.6	639	28.8	53.5	46.5
3	1,902	385	20.2	1,517	79.8	317	16.7	644	33.9	55.8	44.2
4	2,151	404	18.8	1,747	81.2	356	16.5	721	33.5	55.0	45.0
5	2,153	488	22.7	1,665	77.3	360	16.7	665	30.9	51.5	48.5
6	1,823	455	25.0	1,368	75.0	272	14.9	531	29.1	43.8	56.2
7	2,232	427	19.1	1,805	80.9	337	15.1	786	35.2	42.8	57.2
8	2,019	451	22.3	1,568	77.7	300	14.9	648	32.1	48.3	51.7
9	2,157	396	18.3	1,761	81.7	370	17.2	673	31.2	50.6	49.4
10	2,098	364	17.3	1,734	82.7	382	18.2	717	34.2	49.2	50.8
Average	2,077	440	21.2	1,637	78.8	334	16.1	669	32.2	49.9	50.1

No.	Copra.				Milk.		Oil.		Calculated to per cent in nut free from husk.				
	Weight.	Per cent copra in nut.	Per cent oil.	Per cent pulp.	Weight.	Per cent.	Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	324	16.1	61.1	38.9	568	28.2	198	9.8	19.3	43.7	21.1	37.0	12.9
2	342	15.4	40.6	59.4	686	30.9	139	6.3	20.8	38.2	20.5	41.0	8.3
3	360	18.9	51.5	48.5	556	29.2	185	9.7	20.9	42.5	23.7	36.6	12.2
4	396	18.4	58.6	41.4	670	31.2	232	10.8	20.4	41.3	22.7	38.3	13.3
5	343	15.9	58.2	41.8	640	29.7	200	9.3	21.6	39.9	20.6	38.5	12.0
6	233	12.8	60.8	39.2	565	31.0	142	7.8	19.9	38.8	17.0	41.3	10.4
7	336	15.1	58.6	41.4	682	30.6	197	8.8	18.7	43.5	18.6	37.8	10.9
8	313	15.5	54.5	45.5	620	30.7	171	8.4	19.1	41.3	20.0	39.6	10.9
9	340	15.8	52.3	47.7	718	33.3	178	8.2	21.0	38.2	19.3	40.8	10.1
10	353	16.8	51.2	48.8	635	30.3	181	8.6	22.0	41.4	20.4	36.6	10.4
Average	334	16.1	54.7	45.3	634	30.5	182	8.8	20.4	40.9	20.4	38.7	11.1

SERIES XIV.—*Davao nuts, large.*

No.	Total weight.	Husk.		Nut minus husk.		Shell.		Meat.				Copra.	
		Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Weight.	Per cent.	Per cent copra.	Per cent water.	Weight.	Per cent copra in nut.
1	3,070	910	29.6	2,160	70.4	452	14.7	766	25.0	43.7	56.3	335	10.9
2	3,092	725	23.4	2,367	76.6	482	15.6	846	27.4	52.3	47.7	442	14.3
3	2,391	614	25.7	1,777	74.3	308	12.9	763	31.9	53.9	46.1	411	17.2
4	2,737	639	23.4	2,098	76.6	340	12.4	861	31.5	47.7	52.3	411	15.0
5	2,483	752	30.3	1,731	69.7	333	13.4	715	28.8	54.5	45.5	390	15.7
6	2,367	765	32.3	1,602	67.7	320	13.5	686	29.0	43.9	56.1	301	12.7
7	1,897	608	32.0	1,289	68.0	244	12.9	535	28.2	31.2	68.8	167	8.8
8	2,271	663	29.2	1,608	70.8	327	14.4	688	30.3	47.4	52.6	326	14.4
9	2,444	495	20.2	1,949	79.8	330	13.5	794	32.5	49.9	50.1	396	16.2
10	2,526	516	20.4	2,010	79.6	323	12.8	799	31.6	51.6	48.4	413	16.3
Average	2,528	669	26.7	1,859	73.3	346	13.6	745	29.6	47.6	52.4	360	14.2

No.	Copra.		Milk.		Sprout.	Oil.		Calculated to per cent in nut free from husk.				
	Per cent oil.	Per cent pulp.	Weight.	Per cent.		Weight.	Per cent.	Shell.	Meat.	Copra.	Milk.	Oil.
1	59.3	40.7	942	30.7	------	199	6.5	20.9	35.5	15.5	43.6	9.2
2	62.9	37.1	1,039	33.6	------	278	9.0	20.4	35.7	18.7	43.9	11.7
3	60.7	39.3	700	29.3	6	250	10.4	17.3	42.9	23.1	39.4	14.0
4[a]	64.1	35.9	892	32.6	5	263	9.6	16.2	41.1	19.6	42.5	12.6
5[a]	65.7	34.3	680	27.4	3	256	10.3	19.2	41.3	22.5	39.3	14.8
6[a]	64.9	35.1	596	25.2	------	195	8.3	20.0	42.8	18.8	37.2	12.2
7[a]	55.3	44.7	504	26.5	6	92	4.9	18.9	41.5	13.0	39.1	7.2
8[a]	61.0	38.0	589	25.9	4	199	8.8	20.3	42.8	20.3	36.6	12.4
9[a]	63.8	36.2	825	33.8	------	253	10.3	16.9	40.8	20.3	42.3	13.0
10[a]	60.8	39.2	875	34.6	13	251	9.9	16.1	39.8	20.6	43.5	12.2
Average	61.9	38.1	764	30.0	3	224	8.8	18.6	40.4	19.2	40.7	12.0

[a] Oil separated from the milk, hence the nuts were very ripe.

[To be followed by a paper on "The Keeping Qualities and the Causes of Rancidity in Coconut Oil" in the next number of the JOURNAL.*]*

PLATE I. COCONUT PALMS GROWING ON THE BEACH AT SAN RAMON, SHOWING HABITAT.

PLATE II. THE NUTS SET OUT IN THE SEEDING BEDS.

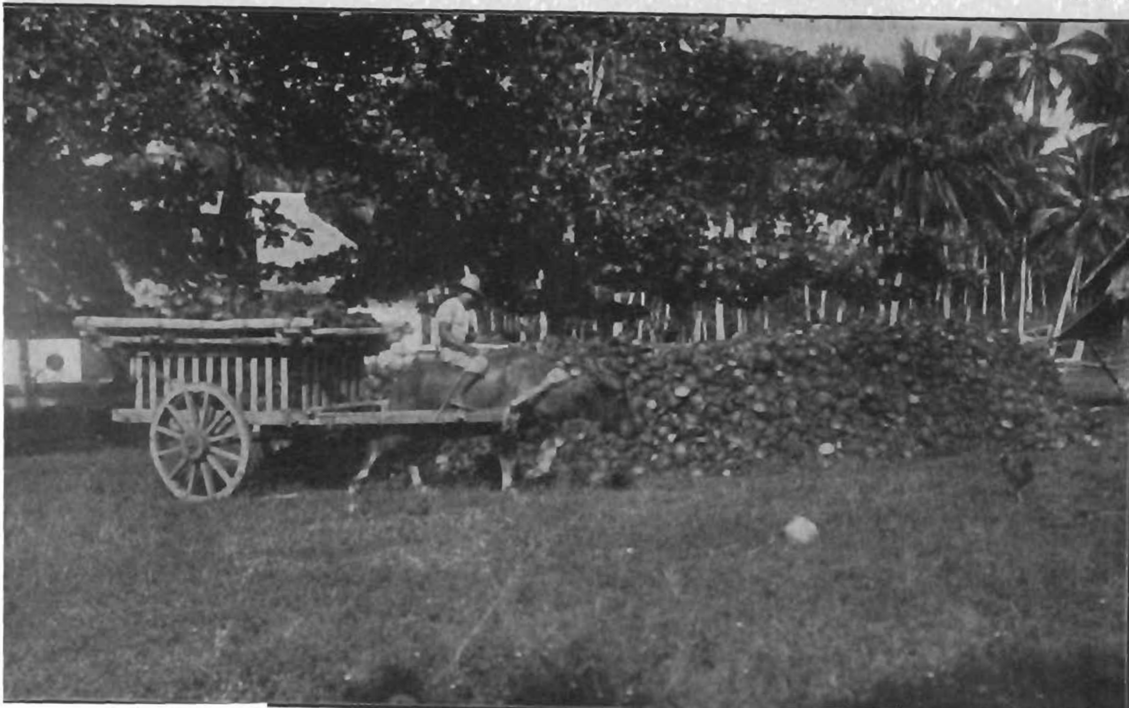

PLATE III. GATHERING COCONUTS IN PILES NEAR THE DRYING SHEDS.

PLATE IV. SORTING AND HUSKING NUTS ON THE BEACH NEAR THE DRYING SHEDS.

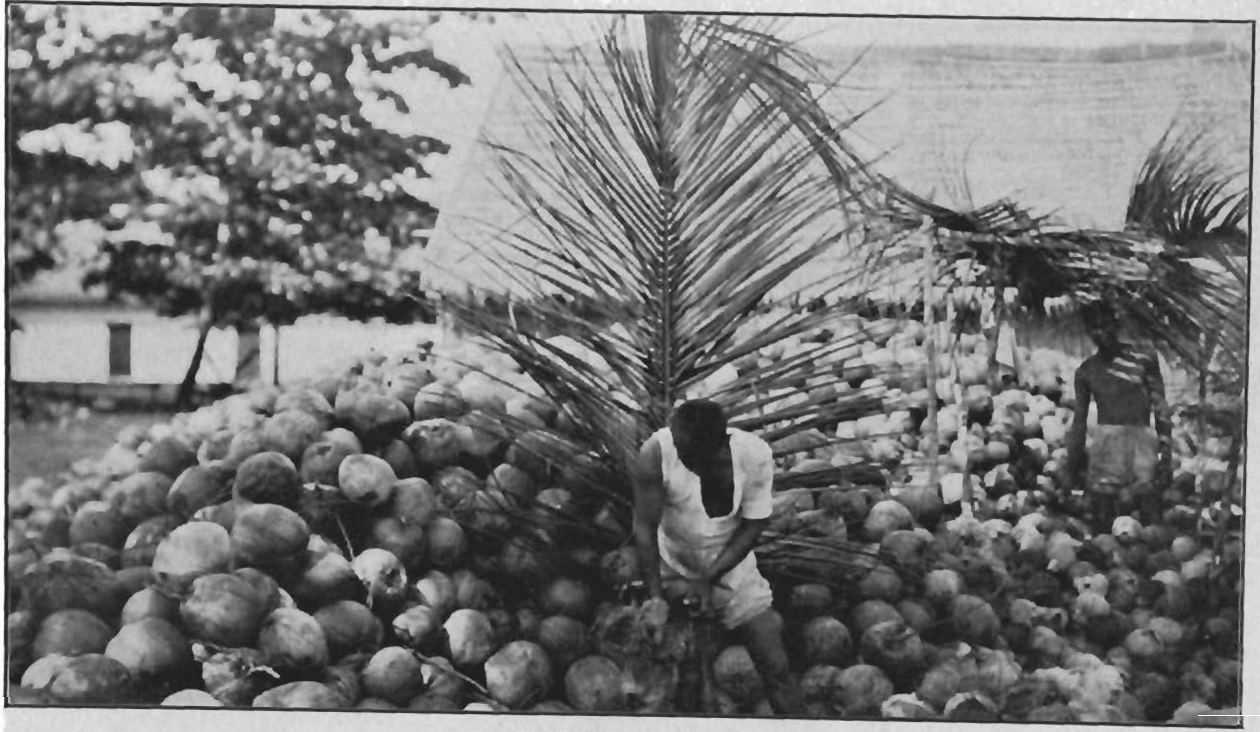

PLATE V. METHOD OF HUSKING THE COCONUT.

PLATE VI. BREAKING OPEN THE COCONUT BEFORE DRYING; THE MILK GOES TO WASTE ON THE GROUND.

PLATE VII. SUN DRYING THE NUTS ON TRAYS.

PLATE VIII. SUN DRYING, SHOWING THE NUTS ON THE TRAYS, READY TO BE PUSHED UNDER THE SHELTER.

PLATE IX. KILN USED FOR DRYING NUTS.

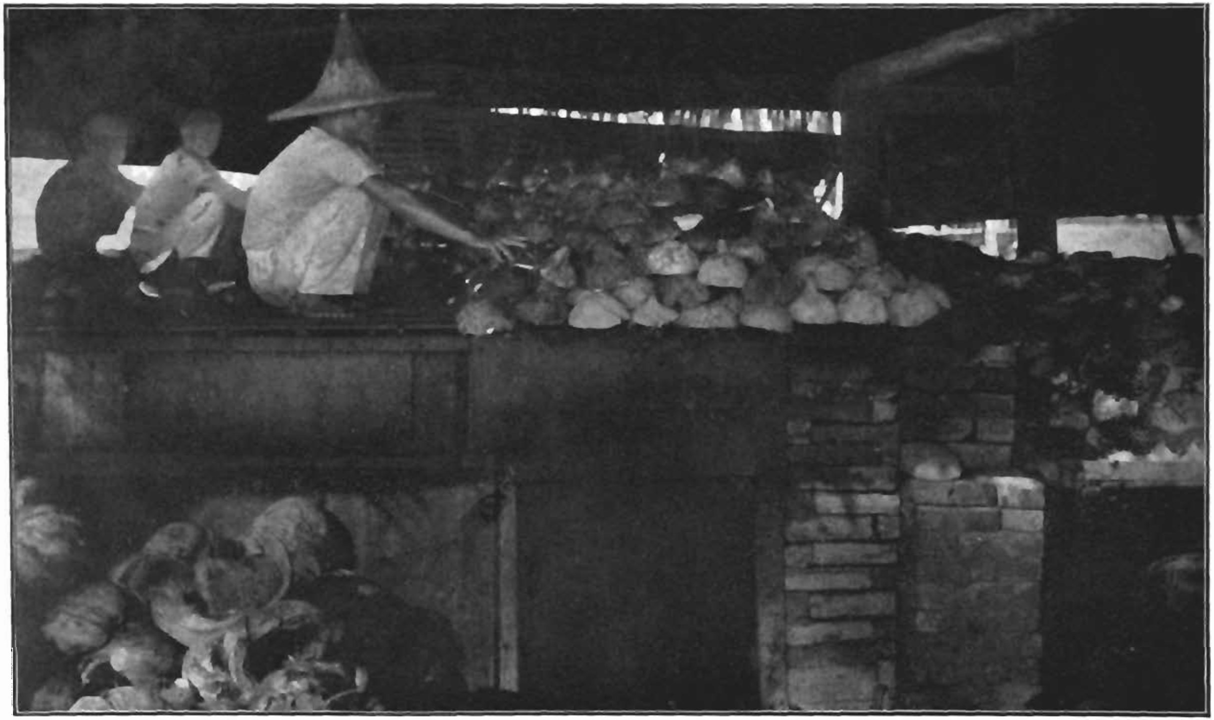

PLATE X. KILN DRYING; THE HALVES OF THE COCONUTS ARE PLACED OVER THE GRILL FOR THE PRELIMINARY DRYING.

THE OCCURRENCE OF SCHISTOSOMA JAPONICUM VEL CATTOI IN THE PHILIPPINE ISLANDS.

By Paul G. Woolley.
(*From the Serum Laboratory, Bureau of Science.*)

As long ago as 1887 Mazima, in Japan, wrote of a peculiar form of liver cirrhosis which was caused by an unknown parasite. In succeeding years his observations received corroboration from various sources. The ova of this parasite were found not only in the liver but also in other organs, and it soon became apparent that the observers were dealing with a definite endemic disease which was more or less closely confined to the Provinces of Bingo, Yamanashi, Hiroshima, and Saga. From a town in Bingo (Katayama) the malady has taken its name, so that in Japan it is known as the "Katayama disease."

In 1904 Katsurada studied fifteen cases of the infection, and in the stools of five found ova which resembled those of *Schistosomum hæmatobium*. Later, in dissecting dogs and cats from an infected district, he encountered (in a cat) flukes within the portal vessels. These he described (August 30, 1904) in a Japanese paper, in which he proposed the name *Schistosomum japanicum* for the parasite. Later, in December, 1904, Katsurada published again on this subject, this time in German, and stated that Fujinami had announced (October, 1904) the discovery of a female *S. japonicum* in a human subject. In the same year, in lesions of the liver, mesenteric glands, and intestines of a Chinaman from the Province of Fukien, China, Catto, at that time resident medical officer of the Singapore quarantine station, found certain bodies which he believed to be coccidia. The case was first reported as one of coccidiosis, but later this diagnosis was changed, and in September, 1904, the claim was set forth that the bodies were the ova of a new parasite. Later still, Blanchard, after seeing Catto's specimens, gave the trematode the name of *Schistosoma cattoi*, and in 1905 Catto described it under that title. Catto based his description upon material obtained from the human subject, while Katsurada based his largely upon that obtained from cats, and this distinction, as Stiles insists, must be taken into consideration.

This being the case, the conclusion is fairly safe that the parasites described from Japan and China are of the same species. It also seems

assured that they are quite different from the Egyptian form *S. hæmatobium*.

Here it is only necessary to say that the worms are characterized by the absence of the ciliated warts on the integument, which are a marked feature of *S. hæmatobium*. Minor anatomic differences are the size of the worm [average 10.43 millimeters (Katsurada)], the length of the vas deferens, and the lobular character of the testes.

The eggs are smaller than those of *S. hæmatobium*, have blunter ends, and no spine.

A complete comparison of the Chinese and Japanese worms and of their ova will be found in Stiles's paper.

The description of the clinical symptoms of the disease "Katayama" must, for the present, be taken from the Japanese reports, since in neither Catto's nor my case was there any opportunity for clinical study.

Katsurada was able to examine from 30 to 54 cases every year while stationed in the infected district, in which his residence extended over about five years. He observed but few deaths (three to five annually) which he considered were directly due to the parasite, but he regards the indirect mortality as much higher. Defective physical development is the rule in affected children. Diarrhœa is usually the first symptom to be noted, while anæmia and ascites generally follow later; however, the most striking feature is the shape assumed by the trunk. The hypogastric region seems to shrink, while the epigastric enlarges, a transverse furrow forming directly above the umbilicus, so that the general appearance of the abdominal region is that of an inverted gourd. Dilatation of the epigastric region and of the lower part of the thorax was noted even in patients whose liver and spleen were not much enlarged. The commonest symptoms are an initial increase in the size of the liver, followed by a decrease, a secondary enlargement of the spleen, a muco-sanguinous diarrhœa, severe attacks of ascites, and progressive anæmia. Katsurada found the ova of the parasite under discussion and also those of *Tricocephalus dispar, Uncinaria,* and *Ascaris lumbricoides* in the stools of his patients.

Yamagiwa described (1890) a case of Jacksonian epilepsy in which he found ova in certain nodules in the brain. These ova were similar to those now known to occur in "Katayama." At the time Yamagiwa first reported his case he considered these ova to be those of the lung distome, but he now believes himself to have been dealing with *Schistosoma japonicum*.

In Catto's case the right lobe of the liver extended for a distance of two fingers' width below the costal margin and the left lobe a hand's breadth below the sternum. The spleen was enlarged.

My case occurred in a native Filipino who had not been out of the Islands and who at the time of his death was in Bilibid Prison. He died suddenly of a terminal bacterial infection in the course of intestinal amœbiasis and uncinariasis. The liver was not enlarged, but the spleen was somewhat increased in size.

The pathologic details of the Japanese cases, as described by Katsurada (Scheube), are as follows:

At autopsy the liver is less than normal in size and its surface is marked by small nodules, larger than those observed in Laennec's cirrhosis and smaller than those of the usual gross form. The capsule of Glisson is thickened. Microscopical observation shows connective tissue increase and round-cell infiltration in the capsule of Glisson in which the ova lie, in part in the lumen or in the walls of the portal capillaries and in part in the connective tissue. There are also fibrous nodules and tubercle-like areas which contain ova, although these are not commonly seen in the parenchyma. In addition to their location in the liver, the eggs are also found in the intestinal wall (especially that of the large intestine), in the mesentery, in the mesenteric glands, the lungs, and the brain. In the intestinal wall they especially occur in the submucosa and often are present in such numbers as to cause the mucosa over them to become bulged out or even eroded. Kanamori (Scheube) found in one case, in the rectum and sigmoid, adenomas resembling the new growths described by Kartulis in *Bilharziosis*. In the lungs and brain the eggs are encountered in tubercle-like masses, surrounded by round-cell infiltration and an increase of connective tissue.

In Catto's case the liver and spleen were both enlarged. The condition of the peritoneum suggested that repeated attacks of peritonitis had occurred. The appendices epiploicæ were thickened and in places were matted together. The recto-vescical pouch was almost obliterated. The mesenteric lymph glands were enlarged. The liver was apparently cirrhotic. The colon was thickened and its mucous membrane was swollen, hyperæmic, and friable, and presented small circular, superficial erosions and patches of necrosis. The rectum was adherent to the bladder. The mucosa of the ileum was congested and formed thickened patches. The stomach, pancreas, adrenals, kidneys, heart, and lungs showed no gross lesions. In sections of the liver, mesenteric glands, and bowel small oval bodies were found which were at first believed to be coccidia. Subsequent examination disproved this and showed them to be the ova of a trematode. Nematode embryos were found in smears from the large intestine and in the vessels of a mesenteric lymphatic gland. In sections of the meso-colon, adult trematodes were found in blood vessels, and in the uterus of one of these were oval bodies corresponding to those seen free in the tissues in other sections. The parent worms were encountered in small groups at the bifurcations of the small mesenteric vessels. Where the ova had accumulated in certain places they had provoked a small-cell infiltration which gave rise to a proliferation of fibrous tissue. In the intestine, from cæcum to anus, the ova roughly occupied two concentric layers—the one subperitoneal where they were comparatively scarce, the other submucous where they were innumerable. They were also plentiful in the mucosa, and more numerous in the necrotic areas, in which situation they were seen apparently to be in the process of extrusion.

The rectum and appendix were the parts most affected in the entire intestinal tract. Ova were found throughout the small intestine, but only in patches and in comparatively small numbers. They were plentiful in the liver, lying singly or in large or small clumps embedded in the hypertrophied fibrous tissue. They were also found in the thickened trabeculæ of many of the enlarged mesenteric glands. Ova were also encountered in the outer wall of the gall bladder, in the pancreas, liver capsule, the fibrous coat of the mesenteric vessels, mesenteric, pylorus, duodenum, jejunum, and ileum. Ova of *Trichocephalus dispar* and *Ascaris lumbricoides* were also seen in the bowel.

The case to be described was one of the series which formed the basis of a report on the pathology of intestinal amœbiasis by Dr. Musgrave

and the writer. During the investigation of the pathologic anatomy of that disease I discovered the presence of the ova which, in the opinion of Shiga, Fujinami, and Stiles, are those of *S. japonicum v. cattoi.*

The autopsy was performed by Dr. Musgrave a few minutes after the death of the patient. There was an old, discharging abscess on the right arm and another on the right side of the thorax extending into the pectoral muscles. The subcutaneous fat was well preserved and the muscles were somewhat pale. The left lung showed an intense congestion, with œdema of the lower lobe. The right was also congested and an abscess, over which the two layers of the pleura were firmly adherent, was present in the lower lobe, binding the lung to the diaphragm, ribs, and sternum. The cavity of this abscess, resembling those seen in amœbiasis, was filled with a thick pus. The abdominal cavity was free from adhesions. The walls of the intestine were somewhat thickened and the mesenteric lymphatics moderately enlarged. The spleen was enlarged and a well-marked chronic perisplenitis was present; it was adherent to the diaphragm, and its surface was wrinkled and pale. The liver showed a considerable perihepatitis and was bound to the diaphragm and abdominal wall by firm adhesions. On the dome was a large scar resembling that resulting from a healed abscess; about this were old and dense adhesions. On section, the liver was pale and cloudy, giving an increased resistance when cut. The kidneys showed a moderate parenchymatous degeneration. The stomach and the small intestine showed a well-marked catarrhal condition, and in the former there were a few small hæmorrhages. In the upper 40 centimeters of the small intestine there were a number of uncinaria. The large bowel gave evidence of amœbic infection throughout, but the most marked pathologic changes were in the transverse and descending colon, and less in the cæcum and rectum. In the most advanced lesions the process simulated a hæmorrhagic enteritis in which small superficial ulcerations predominated. These ulcerations displayed a considerable variety, but the deep-sloughing, undermined ulcer was not present. The appendix was not involved. (Musgrave.)

Microscopically, large numbers of amœbæ were found in scrapings from the ulcers and in the intestinal contents, but none could be demonstrated in the pulmonary abscess. Ova of uncinaria were also present in the intestinal contents.

Tissues from the intestine, liver, and lungs were secured and preserved in Kaiserling's solution. Bits of these were embedded in celloidin and paraffin. Sections were stained with hematoxylin and eosin.

The histological study showed that the mucous membrane of the large intestine was atrophied and, in areas, eroded. The submucosa was thickened and œdematous. The muscular layers presented but little change. The ova occurred chiefly in fibroid tissue in the submucosa, where they were innumerable and surrounded by round-celled infiltration. In the

mucosa they were much fewer, in the subperitoneal layer very infrequent, in the muscular layer absent. In the liver they were confined almost entirely to the perivascular tissues, and were most commonly seen about the intralobular vessels. They also occurred about the interlobular vessels and in the parenchyma. In the lungs they were found only in the tissue about the abscess cavity and were seen in but very small numbers. Wherever they were present they were surrounded by small-cell infiltration and fibrosis.

The following comparative measurements of the ova were furnished to me by Dr. Shiga, after he had examined my specimens and compared them with those of Fujinami and Manson:

	Manson.	Fujinami.	Woolley.
	mm.	*mm.*	*mm.*
Length	0.0728	0.0662	0.0624
Breadth	.048	.0436	.0436

In the opinion of Katsurada these parasites feed upon the blood and in this way produce the anæmia which, according to the Japanese reports, is a common symptom of the disease. He also (see Stiles) suggests that the worms probably form a toxin which perhaps is the cause of the enlargement of the liver. The eggs may form embolisms in various organs, most frequently in the liver, in which they cause inflammation and increase in the connective tissues, producing a type of cirrhosis in which the surface of the organ is coarsely and irregularly granulated. These changes assist in bringing about more or less prominent portal stasis. The eggs in the mucosa and submucosa of the intestine, especially of the colon, cause more or less severe inflammation; resulting in part in the destruction, in part in the formation, of tissue, changes which are sometimes followed by the tumor-like growths described by Kanamori, and sometimes by ulcers.

Katsurada believes that the disease originates from stagnant water. He says that in summer the water standing in the rice fields becomes covered with bubbles which break when in contact with the skin, with resulting itching and eruptions. Infection, then, he thinks takes place through the abraded skin. In places where artesian-well water is used and where the people do not wade in the bubble-covered water the disease is becoming less frequent.

Since visiting the farming districts of Japan I have little doubt but that the disease is a water-borne one and that it originates in the rice fields or irrigated gardens. The same is true of China. In both these countries the fields are fertilized by human excreta to such an extent that in many places traveling is most unpleasant because of the odor. Under such circumstances the opportunities are excellent for the transmission of a disease which is caused by a parasite the ova of which are

passed in the stools. Whether infection occurs through the skin or not is still a question, though from the distribution of the eggs in the body we would suppose that it occurred by the gastro-intestinal route. However, the same is true of uncinariasis, and still there appears to be considerable evidence of the occurrence of the latter infection through the skin.

The significance of this new case is evident. It means that not only in China and Japan but also in the Philippines there is a disease caused by a blood parasite which may of itself, or by its eggs, and perhaps also by a toxin, produce a serious condition resulting in cirrhosis of the liver, splenomegaly, ascites, dysentery, progressive anæmia, and also, possibly, epilepsy of the Jacksonian type. In certain stages of the infection the condition may be confused with tropical splenomegaly, of which it possibly is one of the much-sought-for causes; or with amœbic dysentery or uncinariasis, with either or both of which it may be combined, or with epilepsy. It is very probable, now that a case has been encountered, that further ones will be discovered, and perhaps it will be found to be nearly as common, both in China and the Philippines, as it is in Japan.

The following method of staining the ova in the tissue was devised by Mr. Willyoung, of the Biological Laboratory:

Celloidin sections were immersed in water and then stained in a solution containing 1 per cent acid fuchsin and 2 per cent oxalic acid. They were then washed in water and stained in an aqueous solution containing 0.12 per cent of aniline blue and 1.2 per cent oxalic acid. Differentiation was accomplished by using acid alcohol and 80 per cent alcohol. By this means the ova were stained a brilliant red and the tissue a clear blue.

SUMMARY.

In lesions in the lungs, liver, and the bowel of a Filipino, ova have been found which agree in shape, size, and color with those of *Schistosoma japonicum vel cattoi.*

The lesions in the bowel were ulcerations closely resembling those seen in some forms of amœbiasis; those in the liver were characterized by fibrosis.

The symptoms were not definite, because of the mixed infection with other intestinal parasites.

From these observations it follows that in China, Japan, and in the Philippine Islands there is a trematode worm differing characteristically in its morphology from the allied African species, which produces lesions, especially in the large intestine and liver, and which has been described as *Schistosoma japanicum vel cattoi.* The case under observation is, to the best of my knowledge, the first schistosoma infection encountered in the Philippine Islands, and, therefore, now that it has been called to the attention of investigators, it seems not unlikely that other cases will be discovered.

Since the above was written, a second Chinese case of schistosomiasis has been recorded by Bayer (*Amer. Med.* (1905), X, 578). This case was first observed by O. T. Logan, of Changteh, Hunan, China, who made clinical notes upon the case and who later sent these and specimens of the fæces to the Naval Medical School. The patient, a boy of 18 years, for six years had bloody stools. At 15 years of age he had been incapacitated for hard work. Logan found the liver and spleen enlarged, the latter but slightly. The stools, which continued to show blood, averaged about four in twenty-four hours and were preceded by abdominal pain. The ova of the parasite were found in the feces, and each ovum contained a ciliated embryo. Logan thought the ova were those of *S. japonicum*, and in this view Stiles, Lovering, and Beyer coincide.

From the following articles I have drawn very generously, and to Dr. Stiles and Dr. Shiga I wish to express my gratitude:

CATTO: Schistosoma cattoi: A New Blood Fluke of Man. *Brit. Med. Jour.* (1905), I, 11; *Journ. Trop. Med.* (1905), VII, 70.

SCHEUBE: Ein Neues Schistosomum beim Menschen. *Arch. f. Schiffs- und Tropen-Hygiene* (1905), IX, 150.

STILES: The New Asiatic Blood Fluke (*S. japonicum*, 1904; *S. cattoi*, 1905) of Man and Cats. *Amer. Med.* (1905), IX, 821.

KATSURADA: An Endemic Disease Caused by a Special Parasite Previously Unknown in Japan. *Sei. I. Kwai.*, XXIII and XXIV. (Review in *J. A. M. A.* (1905), XLV, 80.)

LOOSS: Schistosomum japonicum Katsurada, Eine Neue Asiatische Bilharzia des Menschen. *Centr. f. Bakt.*, Orig. (1905), XXXIX, 280.

ILLUSTRATIONS.

In all instances the photographs were made with the Zeiss photomicrographic apparatus, compensation ocular No. 6, objective AA; bellows at 45 centimeters.

FIG. 1.

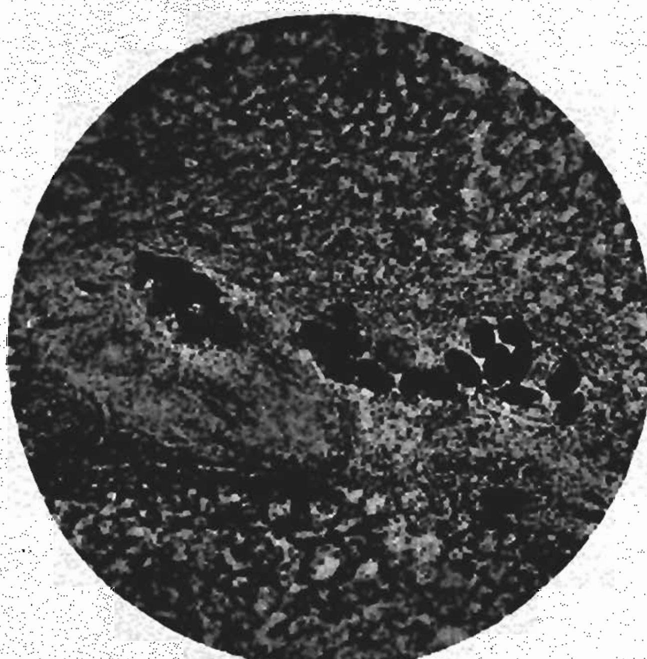

FIG. 2.

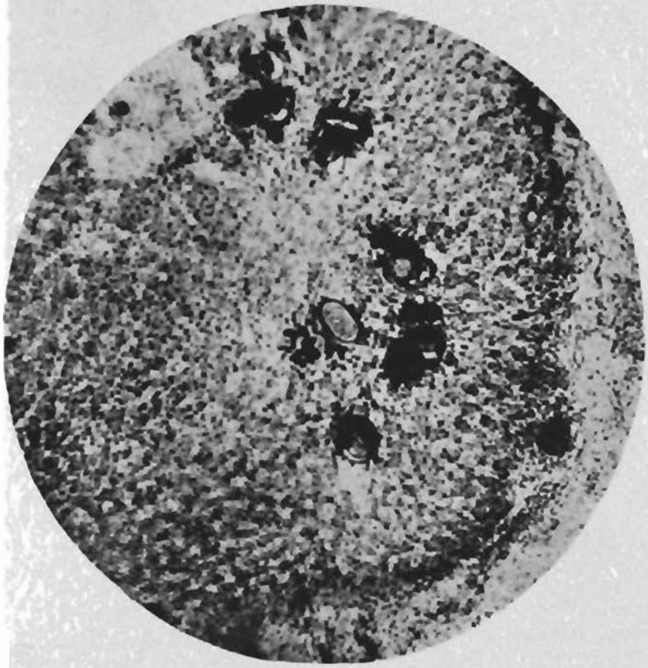

FIG. 3.

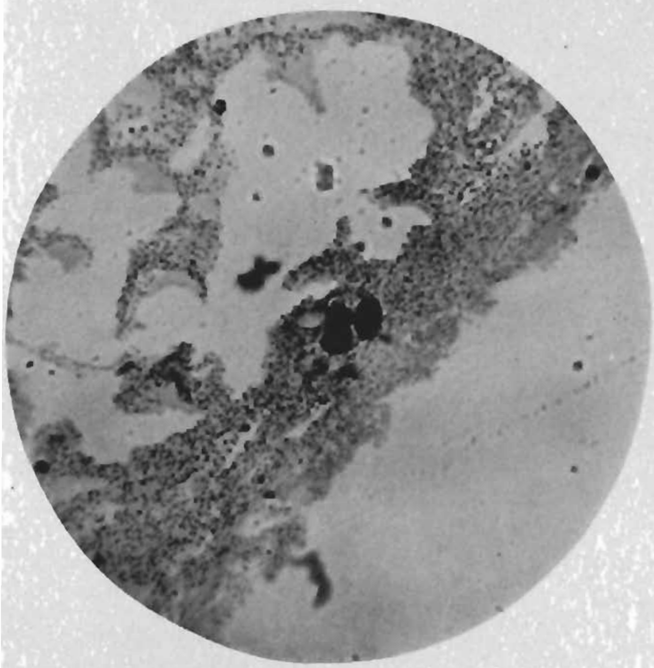

FIG. 4.

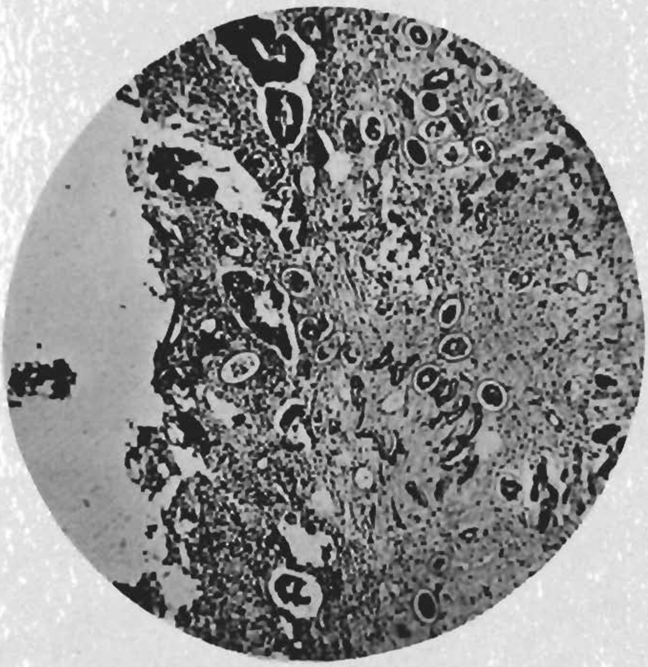

FIG. 5.

A STUDY OF SOME TROPICAL ULCERATIONS OF THE SKIN WITH PARTICULAR REFERENCE TO THEIR ETIOLOGY.

By Richard P. Strong.
(*From the Biological Laboratory, Bureau of Science.*)

In Manila subacute and chronic ulcerations of the skin, of obscure origin, are not infrequently encountered. During the past two years I have examined, particularly from an etiological standpoint, all forms of ulceration of this nature which have come to my notice. So far, twenty-four instances have been studied. Many of the lesions in these cases differed widely in their clinical manifestations, and I was able to demonstrate conclusively that at least several of them varied in their etiology.

It was originally my intention to review in detail the examination of each case; but on going over my notes I found so little which was characteristic or of interest in many of them that I have considered it more advisable here to discuss merely those instances which either proved etiologically to be or seemed clinically to represent distinct and specific infections. Thus, in a number of cases, a history of various primary injuries of the skin was obtained; and although at first it was intended not to include in this study ulcerations occurring in the course of certain chronic diseases, such as leprosy, syphilis, or yaws, nevertheless, of the lesions of seven of the cases investigated, five later proved really to be those of yaws and two of syphilis. Only staphylocci, streptocci, or saprophytic bacilli were isolated in the larger number of the lesions studied. However, in addition to those instances in which, both clinically and etiologically, nothing definite could be discovered, and to the ones which represented lesions in the course of those chronic affections I have mentioned, three distinct clinical types of disease were encountered, and these will now be considered.

ULCERATION OF THE FIRST TYPE.

In the first instance, the lesion to be discussed answers very well, both in its clinical appearance and in its history, to the usual description of *Delhi* or *Oriental boil,* as found in the several text-books on tropical diseases. The history of this case may briefly be recorded as follows: The patient was a native woman about 35 years of age. Approximately six weeks before consulting me she stated that she had noticed a small red

spot on the right side of the chest just below the clavicle and above and to the right of the breast. The lump gradually enlarged, but occasioned little pain. When I first saw the boil it was about the size of a half dollar and had not opened. The skin over the center was scaly, indurated, and reddened. Fluctuation could be obtained. On incising the abscess in the center, a scanty, rather thick, purulent material was found and a small ulcerating cavity, containing soft granulations, was exposed. On the following day, under cocaine anæsthesia, the whole cavity was carefully curetted. The operation was thoroughly performed, because the patient insisted on leaving on the next day for the provinces to be gone for several months. Directions were given for the daily antiseptic dressing of the wound. I was unable to see her again until four months later, when, after repeated requests, she finally returned to the city and exhibited to me a contracted scar the size of a dollar, situated over the original site of the lesion. She reported that the wound had gradually healed, about two months after leaving the city. Portions of the granulations which were removed with the curette were hardened in Zenker's fluid, embedded, sectioned, and stained in hematoxylin-eosin, hematoxylin-picrofuchsin, methylene-blue-eosin, fuchsin, Borrell's stain, and Wright's modification of Romanowsky's method. Figs. 1 to 10, inclusive, are photomicrographs made from these sections.[1]

The histological changes in the portions of the granulation tissue which were removed consist of a chronic inflammatory process in the subcutaneous tissue, with areas of acute inflammation, showing cellular infiltration and in places necrosis, together with considerable fibrin formation. In addition, the infiltration consists of numbers of cells whose protoplasm stains poorly, of fragmented nuclei, polymorphonuclear leucocytes, and small round cells with deeply staining round nuclei. In places the lymph spaces are widened, and there is an extensive proliferation of the endothelial cells of the lymphatic vessels, and in some areas these occur in rows, thus suggesting their origin from their arrangement. There is also considerable proliferation of the fixed connective-tissue cells. Multinuclear giant cells are occasionally observed and plasma cells are fairly numerous. In certain of the inflammatory areas eosinophiles are greatly increased in number and not infrequently many free eosinophilic granules may be seen, but only occasionally a mast cell is visible here. In the sections a striking feature is the presence of numerous large endothelioid phagocytic cells, with a relatively large amount of protoplasm and with a large round or oval nucleus, which may contain a nucleolus. Sometimes the margins of these cells are indistinct. No bacteria are evident in the sections. The presence of parasites, which are scattered throughout the tissue, is of chief interest. These may be described as oval

[1] I wish to express my thanks to Mr. Willyoung, of the Biological Laboratory, for his success and interest in the staining of the parasites in the tissues of this case.

bodies, which resemble cockleshells, with a sharp outline, measuring about 3 to 4 μ in their greatest diameter. In sections stained with hematoxylin and eosin they usually remain unstained; in those treated with picrofuchsin, Borrell's blue, or Wright's method, they are still to a large extent uncolored, but many contain particles of chromatin, which stain and which consist, first, of a rounded mass, which sometimes has the form of a ring, and secondly, of a small dot or rod. These bodies are found in large numbers, both free and inclosed in endothelioid phagocytic cells, or lying in a sort of matrix composed probably of degenerating tissue. As many as ten or twelve may be seen in a single cell. They are very definite organisms and there is no doubt that they are parasites. In not all of the cockleshells are the chromatin masses present and many of them contain either the ring body or the pigment dot or rod alone (figs. 5 and 9). In fact, it is somewhat exceptional to see both chromatin particles in the same parasite; or, at least, either the one or the other body alone is in focus at one time. The shape of the chromatin masses also sometimes varies. Frequently, seal-ring-like forms are encountered (see figs. 7 and 10), or again at times a crescentic mass of pigment is seen situated alone at the edge of the ring. Such examples may be observed in figs. 3 and 4. With Zeiss objective DD and ocular 3 the organisms appear as small dots and oval bodies, often lying free, but generally inclosed in phagocytic cells. Their appearance under this magnification is illustrated in fig. 2. The further discussion of these organisms will be taken up below. Agar cultures which were made at the time of the curetting of the lesion remained sterile.

I do not wish to be misunderstood as insisting that the lesion in this case should be regarded as identical with Delhi boil, but merely to call attention to the fact that both in its clinical and in its histological appearance it has many points of resemblance to the latter affection. Unfortunately I did not obtain any skin immediately over the surface of the boil from this patient. A small portion which was secured from the edge of the lesion does not show any destruction of the papillary layer, though this shows cellular infiltration near the edge of the section. However, this process is more marked in the reticular and subcutaneous strata. As will be referred to presently, the diagnosis of Delhi boil is frequently extremely difficult since the affection presents so little that is distinctive and characteristic.

ULCERATION OF THE SECOND TYPE.

The second type of ulcer, when first seen, clinically differed very much from the one just described. The patient was a native man 25 years of age. The ulcer occurred in the region of the right shoulder, as may be seen from fig. 14. No history of injury to the skin or of trauma was obtained. The patient stated that a little over two months before I saw him, a small, red "spot" appeared over the right shoulder. This gradually enlarged, became hard to the touch, slightly painful, and finally a little fluid began to escape from the surface of the sore. Later the lesion became covered with a black scab. After this condition had

lasted for about six or seven weeks, during which time the sore slowly increased in size, he consulted a native physician, who first poulticed the area and then treated it with antiseptic dressings. About two weeks later he came to Manila for treatment, a diagnosis of tropical ulcer having been made, and he was referred by the Civil Hospital to the laboratory for examination. The lesion revealed the condition shown by fig. 14. There was no longer any scab covering the entire area, though here and there, over the surface of the lesion, there were a few hardened crusts, and in other places small patches of a pseudomembrane of a grayish color. These patches may be distinguished in the figure. In general, the surface of the ulcer was moist and covered with a yellowish-gray, purulent exudate. The base was very uneven and was covered with areas of necrotic tissue or with fresh granulations. The edges were undermined. In depth, the lesion extended through the entire skin and into the subcutaneous tissue and in places the muscle was just exposed. Dr. Cook, of the Civil Hospital, has kindly informed me that after curetting and antiseptic treatment, this ulcer, finally, after three months, healed and the patient was discharged, cured.

The lesion, in this case, when first observed by me, seemed to correspond very well with the description of "tropical sloughing phagedæna," as it is described by Manson, although the physical condition of the patient was otherwise good and the development of the ulcer did not occur exactly as Manson describes it. It is perhaps unnecessary to add that the lesion in this case was not syphilitic.

Film preparations from various portions of the ulcer were made on cover glasses, and these were examined both in a fresh condition and after drying and staining. While numerous, short, thick bacilli and a few cocci were found to be present in these films, nothing which suggested protoza or other parasites was observed. No tubercle bacilli were present. Portions of the tissues were excised for histological study, and agar plate cultures and bouillon tubes were prepared from the lesion, the oese being pushed through the soft granulations and also beneath the overhanging margins of the skin. After twenty-four hours the plate cultures developed numerous colonies, the great majority of which closely resembled one another. In fact, the cultures were almost pure. Colonies occurred on the surface and in the depth of the media. Usually most of those on the surface were round, whitish-gray, and moist. Under a low magnification they were often nucleated and their margins were frequently uneven. There was little which was characteristic about them. Microscopical preparations, which were made from a number of colonies, showed the organism to be a short bacillus, measuring about 1.5 μ in length and about 0.6 μ in breadth. Its motility was only moderate, although later, numerous flagella were demonstrated. When inoculated in gelatin, rapid liquefaction of the medium occurred, with hair-like projections in the line of the stab. Litmus milk was very slowly coagulated.

The reaction was but little changed. Glucose and saccharose were fermented but not lactose. Indol was rapidly produced. The growth on potato was abundant, grayish, and moist. The other colonies, which had a different appearance and which developed on the plate cultures, proved to be those of *Staphylococcus aureus;* they were not by any means so numerous as those of the bacillus just described. Two guinea pigs were inoculated intraperitoneally and one rabbit intravenously, each with one-third of a twenty-four agar slant culture of the bacillus, suspended in saline solution. The animals remained alive and no pathological effects were noted. A small area of the skin over the abdomen of a monkey was shaved and the animal inoculated subcutaneously with 1 cubic centimeter of the bouillon culture from the human lesion. This culture was known not to be pure; it contained, besides large numbers of bacilli, a few cocci. The animal died from asthenia three weeks after the inoculation. It had been long in captivity and was somewhat emaciated at the time of its death. At autopsy, cultures taken from the heart's blood, liver, and spleen all remained sterile. On the abdomen, near the point of inoculation, was a small nodule, measuring about 1 centimeter in diameter, over which the skin was reddened and almost perforated. On incising this area an ulcer, the edges of which were ragged, infiltrated, and undermined, was found in the subcutaneous tissue and corium. A small amount of pus was present. Many cultures from this lesion developed a large number of colonies of *Staphylococcus aureus,* but only a few of the bacillus above described. This latter organism was regarded as a variety of the *Proteus* group. On account of its apparent nonpathogenicity for animals, no further attempt was made to identify it more closely.

The tissues from the human lesion were hardened in Zenker's solution and stained in hematoxylin-eosin, methylene-blue-eosin, carbol fuchsin-methylene-blue, Weigert's stain, and Wright's modification of Romanowsky's method. A histological examination of the sections reveals, usually upon the surface of the ulcer, a dense homogeneous layer, in which the structure of the tissue can no longer be recognized and which stains diffusely red with eosin. Scattered here and there through this mass may be seen numbers of polymorphonuclear leucocytes and in places a large amount of fibrin can be detected. In the upper portion of this necrotic tissue the bodies of the cells do not stain at all, the polymorphonuclei in many instances appearing as if they were lying in clear vacuoles; in other cases the cell protoplasm is stained partly or wholly light pink. A little deeper in the tissue the number of polymorphonuclear leucocytes is greatly increased and the protoplasm of these cells stains well with eosin. Many red-blood corpuscles as well as many fine threads and coarser fibrils, lying between the cells, can be distinguished. These fibers, in specimens stained by the Weigert method, are seen to be fibrin. In other places, in this portion of the tissue, a dense coagulation of the liquid exudate (evidently first secreted) has also taken place, in which

the fibrin masses and cells may be distinguished. The process near the surface may therefore be said to represent an extensive coagulation necrosis. When the lesion is examined with the naked eye, these homogeneous necrotic masses of tissue, in which much fibrin is deposited, give rise over portions of the surface of the ulcer to the very striking pseudomembranous appearance, already referred to. Deeper still in the section the connective-tissue cells are seen to be very greatly proliferated and in places plasma cells are plentiful in number. In other portions of the tissue, the connective-tissue fibers are pushed apart, and there are other evidences of inflammatory œdema. Between these fibers may be seen a few small round cells, red-blood corpuscles, and polymorphonuclear leucocytes. The condition of the blood vessels in which there is a considerable proliferation of the perithelial cells, is quite striking in these areas of inflammatory œdema. The process is particularly well marked about the veins. In many of the vessels the polymorphonuclear leucocytes within their lumina are increased in number, and sometimes these may be seen lying between the several layers of the meso and perithelial cells, which partly form the wall of the vessel. Near these areas large multinuclear giant cells are occasionally observed. Very few eosinophiles are present, and only occasionally a plasma cell is here seen. Scattered through the section are numerous other areas of necrosis, in which, generally, considerable fibrin is present and in which there are also numerous red-blood cells, small round cells, polymorphonuclear leucocytes, fragmented nuclei, much granular material, and many bacteria. Eosinophiles are not seen in these situations; but bacilli, which only partly decolorize by Gram's stain, and cocci, which retain the latter, are encountered usually lying between the cells. No bodies resembling protozoa and no tubercle bacilli appear to be present. In a section at the edge of the ulcer, which includes some of the epidermis, the cells of the Malpighian layer are proliferated. In places, this layer is extensively infiltrated and sometimes apparently destroyed, the area of infiltration and necrosis reaching from below upward to the corneal layer, which it touches. Evidently in this way new foci of ulceration are formed. In centain areas the corneal layer has entirely disappeared. In these places of necrosis an appearance similar to that which has been described in regard to the subcutaneous tissue is seen—coagulation necrosis, deposits of fibrin, fragmented polymorphonuclear leucocytes, etc. The papillary and reticular layers are also extensively infiltrated with round cells and polymorphonuclear leucocytes; in addition both of these strata contain areas of necrosis similar to those already described. The histological appearances are pictured in figs. 15 to 18.

The lesion in the monkey histologically consists of an abscess cavity in the corium and subcutaneous tissue, about which there is little which is characteristic. The pathological changes encountered appear in many ways similar to those seen in the human lesion; but the process is less chronic and there is no proliferation

of the cells about the blood vessels. Cocci and a few bacilli, together with much granular material and many degenerating cells, are distinguishable in the abscess cavity.

As a result of this study the etiology of the human lesion in this case must remain obscure, at least, so far as the discovery of any single specific organism is concerned. Attention may again be called to the fact that no protozoa were encountered in the sections. That the *Proteus bacillus* and the *Staphylococcus aureus,* occurring in symbiosis, alone were responsible for the original lesion seems unlikely. However, there can be little doubt that these bacteria modified and caused an extension of the disease process. It is possible, even if not probable, that the organism responsible for the initial lesion in this case had already disappeared from the ulcer when I had the opportunity of examining it.

ULCERATION OF THE THIRD TYPE.

The third type of ulceration was observed in three cases—the first in a teamster, the second in a mechanic employed in an iron foundry, and the third in a male nurse. All of these were white men.

Although I have been unable to discover the specific organism for this affection, it evidently varies both in its origin and nature from the two forms of ulceration already described. For this reason, as well as on account of the peculiar type of the lesions, it has been thought of importance to call attention to them and to describe the cases somewhat in detail. In all three the ulcerations were multiple and were situated on the hands and forearms. In only one of the cases did the lesions occur elsewhere; in this instance they were situated on the feet and ankles; although they were not present here at the time I was able to study the case. Figs. 19 and 20 very well represent the distribution of the lesions in two of the cases. There were no general disturbances and there was very little or no itching. The lymphatic glands in the region of the elbow were the only ones which were swollen, and these were very slightly enlarged. One of the most striking features of the affection is its extreme chronicity. The disease usually commences by the formation of several small vesicles, which sometimes break and later form superficial ulcerations. In other cases, the vesicles become pustular before opening through the surface of the skin. Areas of fresh infection seem to occur from the older lesions, though I have not been able to entirely verify this fact from a microscopical study of sections. The ulcerations, as a rule, are shallow and but slightly painful; their margins are smooth; they do not have a punched-out appearance and they are not undermined. Their edges are reddened but not indurated. The skin for about 1 or 2 centimeters surrounding the ulcer is also erythematous. There seems to be little tendency for thick crusts to form, but small, soft, yellow scabs are frequently seen scattered over the surface. There is but little discharge; when it occurs it is usually of a serous nature. After several

weeks or months the ulcerations gradually heal; but others quickly form in the adjacent areas of the skin. In one of the cases the lesion persisted for a year and a half, in another for nine months, and in the third (see fig. 20) for nearly three years. Nodules which have not yet broken down, shallow ulcerations, and scars of old lesions may be distinguished in the photograph. In addition to the ulcerations, there are usually to be seen nodular thickenings of the skin and subcutaneous tissue, which have not yet broken down. The skin over the unbroken nodules is reddened. Occasionally these nodules become covered with scales for some time before opening; when they ulcerate, there is only a very small amount of pus present. Potassium iodide and mercury seem to exert no effect on the course of the disease.

Cultures from the ulcerations of two of the cases developed pure growths of *Staphylococcus aureus,* while those from the third showed colonies both of this organism and of those of *Staphylococcus albus*. In one of the cases cultures were taken from an unbroken nodule and these remained sterile. Therefore, the infection does not appear to be of bacterial origin; though it must be emphasized that I was not able to inoculate any cultures in the vesicular stage. The nature of the lesions suggests in some respects that they are blastomycetic in their causation. However, none of these organisms could be discovered in sections.

In one of the cases the histological examination of a section from one of the nodules, which had not perforated the skin, shows in the subcutaneous tissue a cellular infiltration about a vein. The process consists of a true endo-, meso-, and peri- phlebitis. The proliferation may be seen beneath the endothelial layer of cells lining the vessel and extending outward into the surrounding subcutaneous tissue; it consists chiefly of endothelial cells, small round cells poor in protoplasm, and a very few plasma cells. Practically no polymorphonuclear leucocytes are visible and eosinophiles also are not observed outside the vessel; there is in addition early but extensive proliferation of the fixed connective-tissue cells.

As may be seen from fig. 21, the infiltration is eccentric and does not include the whole circumference of the vessel wall. A short distance from the vein the tissue appears normal. Several other foci of infiltration of a similar character are found in the subcutaneous tissue and one in the papillary layer, but none of these are about blood vessels. In sections stained by Weigert's method, no fibrin is demonstrable in these areas. There is no infiltration around the hair follicles or sweat glands and no marked œdema of the tissue. The papillary layer is in general unaffected. Indeed, the section, apart from the areas of infiltration already mentioned, appears normal.

In a section of tissue taken from near the edge of one of the ulcerations a small area of degeneration chiefly composed of degenerating cells of the mucus layer may be seen in the Malpighian layer. In many cases

only the distorted and deeply staining nuclei of these cells can be seen, the protoplasmic portions having disappeared. In addition, small round cells and a few leucocytes are present. No fibrin and no bacteria or other parasites can be detected. Beneath this area in the corium there is infiltration with small round cells. The microscopical picture is somewhat similar to that which Gilchrist has described in the papillary variety of *erythema multiformæ.* In other portions of the tissue in the region of the ulcer similar areas of degeneration may be found in the papillary layer of the corium. In a section of one of the ulcerations near its edge there may be seen on the surface a superficial layer of coagulation necrosis, in which fragmented nuclei and polymorphonuclear leucocytes are present. A few cocci may be distinguished in these areas. A small amount of fibrin can also be demonstrated. In places the necrosis does not extend below the corneous or the mucus layer, being entirely confined to the epidermis. In other portions of the section the papillary stratum is exposed, which then also shows inflammatory infiltration.

The lesions of this affection bear some resemblance to those described by F. Plehn[3] in his mild cases of "ulcerative dermatitis," but the distribution of the ulcerations is different. The disease seems to bear no resemblance whatever to the affection known as *chappa,* as described by Read, or to that of *Pian bois,* by Darier and Christmas.[4] Perhaps in the ulcerative stage it might be considered as one of *veld sore,*[5] in which secondary infection has occurred, but until its etiology is discovered, it is difficult to classify such an affection. By some observers it might perhaps even be considered as belonging to the type known as *Oriental sore.*

CONSIDERATION OF THE ETIOLOGY OF DELHI SORE OR BOIL.

During the past few years the study of one form of tropical ulcer has assumed renewed interest, chiefly, perhaps, owing to the discovery by J. Homer Wright, (1) in 1903, in a case of *Delhi boil,* of certain bodies which have considerable resemblance to the organisms already described by Leishman and Donovan in cases of tropical splenomegaly. While, in general, the clinical descriptions of this type of tropical ulcer (*Delhi boil* or *Oriental sore*), as found in several of the text-books on tropical diseases agree quite closely, when one examines into the clinical features, as set forth in the individual papers of those who have made special studies with reference to the etiology of this form of ulcer, considerable differences in the descriptions are found. Indeed, in many of these articles the reports of the macroscopical appearances of the lesions vary so widely that one is almost led to conclude that more than one type of the disease has been described under the name of *Delhi boil.* Such an opinion is not

[3] *Die Kamerun Küste,* Berlin (1898).
[4] *Ann. derm. et d. syph.* (1901).
[5] Harman, *Journal Pathology and Bacteriology* (1903).

entirely new. Geber, (2) as early as 1874, doubted that such a disease *sui generis* existed, and he further maintained that there was much abuse of the term *"Aleppo boil,"* because lupus, scrofulous, and syphilitic lesions were frequently described under this name. The statement of James, (3) one of the most recent contributors on this subject, is also suggestive of the idea above given. He expresses the opinion that the appearance of some true *Oriental* or *Delhi "sores"* is by no means as characteristic as one would expect it to be from the descriptions given in books. Inded, James found that several surgeons whose experience with the disease was extensive, were unwilling to express a definite opinion as to whether a given sore was really *Oriental sore* or whether it was an example of the ordinary chronic ulcer so common among the natives of India. He emphasizes the fact that *Oriental sore* does not always present very definite characteristics and states that in two of his cases the diagnosis was at first mistaken, the sore in one instance being considered primarily as a form of ringworm and in the other as an ordinary *"shoebite."* The gross appearance of the lesions in a number of the cases which James studied etiologically also varied widely.

Plehn, (4) in his very recent article on this subject, calls attention to the fact that it has not been thoroughly established that the symptom-complex described by the various authors and observers in different regions under the name of *"Beulenkrankheit"* represents a single distinct affection. According to him, some of the descriptions of the lesions might apply to those of furunculosis or of tertiary syphilis or of lupus, and he feels convinced that such errors in diagnosis in the ulcerative stage of the lesion, have certainly occurred frequently. Plehn further comments upon the fact that only in Jeanselme's recent article is frambœsia considered in the discussion of the differential diagnosis, and although he emphasizes the fact that he does not consider the two affections identical, nevertheless, he believes that in their external appearances as well as in their histological structure they in some respects show so great a similarity that any one who is familiar with only one of the affections could occasionally mistake it for the other.

Jeanselme (5) in his article states that, while the *boulon d'Orient* may have a typical aspect and evolution, numerous clinical varieties may also exist. These he describes, and in the discussion of the differential diagnosis of the affection, the lesions of syphilis, of lupus, of leprosy, and of yaws are considered. He also refers to the presence of a lymphangitis in association with the lesion which extends from the region of the ulcers and causes a swelling of the adjacent lymphatic glands. The normal condition of the glands in *Oriental sore* has usually been emphasized by other observers as an important symptom in the differentiation of this affection from " yaws." Kaposi's (6) and Duhring's (7) clinical descriptions of the malady vary so widely that some investigators have doubted whether these authors observed the same affection.

However, not only from a clinical standpoint do the descriptions in the literature differ, but also from a pathological-anatomical one, the reports of the histological appearances either showing considerable variation in the lesions, or, at least, nothing sufficiently characteristic to make an accurate diagnosis of the condition possible. Obviously, these descriptions might be expected to vary greatly in the different stages of the affection, since after the lesions have progressed from the "boil" stage to the ulcerative one and secondary infections have occurred and cicatrization has resulted, the appearances must differ considerably from those seen in their incipiency, and hence the diagnosis of the affection from a pathological standpoint is attended with additional difficulties.

Cunningham, (8) who in 1885 described peculiar parasitic organisms in the tissues of specimens taken from this disease, states that, apart from the presence of these organisms, the lesion presented no specific characters, but was essentially a simple granuloma, such as might arise in connection with the presence of persistent irritation dependent upon various causes.

Babes, (9) in his consideration of the pathology of *Oriental* boil, remarks that one is unable to distinguish the condition from an etiological standpoint, because the pathological changes are not sufficiently different from those frequently encountered in various other boils or furuncles.

Allusion has already been made to the similarity in the pathological conditions which Plehn refers to in yaws and *Delhi boil,* while in the articles of Riehl, (10) Leloir, (11) Unna, (12) Kuhn, (13) and Jeanselme differences in the histological changes are also mentioned; some of which, it is true (but probably not all), depend upon the stage in which the lesion was examined. Kuhn, in his article on the histology of "endemische Beulen," emphasizes the fact that but few characteristic changes were found, though it must be mentioned that from a study of the literature and photographs he concluded that endemic boil exists as a disease *sui generis.*

It is not my purpose here to enter into any further discussion of the literature in regard to this question, since the references given above will, I believe, convince the reader that confusion has occurred in the diagnosis of this disease, and it is more than likely that several different affections have been described under the terms *Delhi, Aleppo, Biskra, Gafsa boil. oriental bouton* or *sore, tropical ulcer, Pendjeh, Yemen, Sarten ulcer,* etc.

One might then be prepared to expect that many specific organisms should have been reported for this type of ulcer, and indeed such is the case. However, many of these observations have to-day only a historical interest or value.

In 1868 Smith (14) believed that he had succeeded in finding, in the sections of a tropical ulcer, ova of a species of distoma. Fleming, (15) in 1873, also thought that he had encountered the eggs of some parasite in the tissues from a case of *Delhi boil.* However, later he attributed another significance to the

bodies which he had mistaken for ova. Carter (16) in 1875, found in an ulcer of the lymphatic spaces of the corium, the mycelium of a fungus which contained many spores and orange-colored granules. However, as other observers have remarked, Carter's specimen had been kept for a long time in a weak preserving fluid which contained no alcohol and in which it probably became contaminated with the mold in question. In 1884, Deperet and Boinet, (17) in the study of an epidemic of *Oriental boil* among soldiers who returned from Tunis, cultivated a coccus from the lesions. This organism proved to be pathogenic for animals and upon injection produced nodules and ulcerations and sometimes a general infection. In the same year Duclaux and Heydenreich (18) also cultivated a micrococcus which they believed to be specific, from cases of *Biskra bouton*. This organism, when injected into animals in small amounts, sometimes produced a chronic lesion of the skin, which was said to bear some resemblance to that of *Biskra bouton*. In other cases the injection of this coccus caused the death of the animal within sixteen hours. Sufficiently accurate details for the identification of the organism are not given.

In 1885 Cunningham (8) reported the discovery of peculiar parasitic organisms in a specimen of *Delhi boil*. The lesion, which was examined histologically, had been placed in alcohol immediately after its removal. The epidermis over the boil was still intact, there being no ulceration present. The organisms varied considerably in size and in form; in some cases they were circular, in others elliptical, and in others irregularly lobate. In the majority of the instances their contour was smooth, but in some it was of a more or less tuberculate character. In some specimens a very delicate cell wall was clearly visible; in others it was wholly unrecognizable, or only to be detected on careful and special scrutiny. Cunningham further states: "The distinctness with which they appear in sections treated with Gentian violet is due to the elective staining by the dye, of the nucleoid bodies which they contain. The number of such bodies present in different cells is extremely variable. The cytoplasm in the gentian-violet specimens remains almost uncolored; in those in which fuchsin has likewise been employed it frequently shows a more or less pronounced red hue. The tuberculate appearance presented by some of the cells is due to the numbers and size of the nucleoid bodies present in them, which in association form a mulberry-like mass pressing upon the cell wall and molding it to the inequalities of its surface. In certain cases appearances apparently corresponding with the occurrence of processes of cell division are present, the bodies of the cells being strongly constricted so as to form two lobes connected by a narrow neck, or two distinct cells occur which, from their relations to one another and the character of their opposed surfaces, seem to have just arisen and to be due to the completion of such a process. The individual cells in some cases are closely packed among the surrounding lymphoid elements; however, in a large number of instances, they appear to lie in a limited clear space. The number of cells visible in individual sections and in different parts of the same section varies considerably. Entire fields may in certain places fail to show any at all. This failure may in many instances be due to imperfect success in staining, but, allowing for this, there can be no doubt that the numbers present in different parts of the tumor vary greatly. It is only quite exceptionally that any are present in the epidermal stratum. The continuous stratum of granulation tissue beneath the papillary layer is the site in which they occur in greatest quantity, but specimens are also frequently present in considerable numbers within the papillary eminences. Their distribution is not limited to the epidermal and dermal strata, for on passing downward to the subcutaneous tissues scattered specimens may be found in the very deepest parts." Cunningham is inclined to regard these bodies as representing various

stages of the development of some simple parasite of mycetozoic nature and concludes that they probably belong to the group of *Monadinæ*. However, he expresses the opinion that it is impossible to come to a definite conclusion as to their nature or to the relation which they bore to the disease.

As Wright (1) has remarked: "From Cunningham's description of these bodies the morphological evidence adduced in favor of their parasitic nature is not sufficient to overcome the objection that they are elements of the tissue or degeneration products."

Nevertheless, while it is true that Cunningham's illustrations do not definitely show that the bodies in question are parasitic in nature, they are equally or even more convincing of the presence of parasitic bodies in *Oriental sore* than are a number of the drawings in some of the very recent articles on this subject.

Riehl, (10) in 1886, found in a single case of this disease a capsulated micrococcus which occurred particularly in the cytoplasm of large epithelioid cells. As many as twenty of these organisms were encountered in a single cell. Cultures from the lesion developed no growth. In the same year, Loustalot and Leloir (19) cultivated a micrococcus which they considered specific, but which Leloir later concluded to be only a variety of the common *Staphylococcus aureus*. Neuijmin (20) also in 1886 found in sections and nodes of 104 cases of *Pendjeh ulcer* a micrococcus which occurred singly, in pairs, or in short chains. No specific characteristics for the organisms were detailed.

Finkelstein, (21) in 1887, in three cases of *Pendjeh ulcer*, and Chantemesse, (22) (1887) in a case of *Nile ulcer*, also cultivated cocci which were believed to be similar to the organism described by Duclaux. In Chantemesse's case the boil had not perforated at the time of the examination. He inoculated a man by piercing the skin with a needle infected with the coccus obtained from the lesion in culture. After five days an abscess formed at the point of inoculation. Two days later this opened and a small, round, crater-like ulcer was exposed, which healed after treatment with antiseptics for some days. However, the organism cultivated from the lesion of Chantemesse's case showed but slight variations from some strains of *Staphylococcus aureus*.

Poncet, (23) also, in the same year, found in sections of a case of *bouton de Gafsa*, two species of bacteria, one a micrococcus and the other a long, thin bacillus. The coccus stained by Gram's method, but the bacillus became decolorized.

In 1888 Heydenreich (24) published his investigations upon a series of twenty-seven cases of *Pendjeh ulcer*, in which he concluded that the disease was caused by the *Micrococcus biskra*, which, together with Duclaux, he had already described in 1884. This organism was said to possess a capsule and to produce spores. Both the coccus isolated by Heydenreich and the other organisms isolated by the various observers prior to the time of his report are to-day believed to be merely species of *Staphylococcus aureus*.

In 1888 Raptschewsky (25) was unable to confirm the results of Heydenreich on the etiology of *Pendjeh ulcer* in cases which he studied and which came from the same region. Instead, he cultivated from the lesions a *Streptococcus*, and, sometimes in association with this, *Staphylococcus aureus*.

In 1894 Le Dantec and Auche (26) also found, in an ulcerated case of *bouton de Biskra*, a *Streptococcus* and *Staphylococcus albus*.

In 1897 Nicolle and Nourry-Bey (27) in nine cases of *Aleppo boil*, some of which had not perforated the skin, found in the blood and pus a streptococcus which they believed to be specific, particularly because of its reaction with Marmorek's serum.

Usually the organism exhibited but little virulence in animals, and the authors were unable to communicate the disease, even to monkeys. In three cases they also encountered staphylococci in association with this organism, and in one each a bacillus and a streptothrix, respectively.

In the same year, Brocq and Veillon (28) cultivated, from a case of *Aleppo boil*, a streptothrix, which, according to Legrain, was similar to the cladothrix of Madura foot. Inoculation into man was without result.

Djelaleddin-Moukhtar (29) also found a streptococcus in a case of *Aleppo boil* which he believed to be identical with the streptococcus of erysipelas.

Crendiropoulo (30) encountered in Camaran, in numerous cases of the Yemen ulcer,[6] a small bacillus together with different saprophytic organisms and pyogenic cocci. A detailed description of the organism is given in his article. It was pathogenic for rabbits and doves, in large amounts causing septicæmia and in small amounts local infection and ulcerations which contained but little pus. Babes concluded that this organism probably belongs to the *Proteus* group of bacteria. Such bacilli he frequently encountered in chronic ulcerations of the skin in connection with the pyogenic cocci.

In 1891 Firth (31) claimed that he had also found, in the lesions of *Delhi boil*, the bodies described by Cunningham. He proposed the name *Sporozoa furunculosa* for the parasite, although he did not give any more distinctive proof than Cunningham that the bodies which were encountered by him were really of a parasitic nature.

In 1898 Borowsky (32) in the study of twenty cases of *Sarten ulcer* constantly found in the secretions and in the ulcers themselves certain organisms which resembled protozoa. In the hanging drop, the parasites had an active motility and were spherical or spindle shaped. They measured from 0.5 to 3 μ in size. The cell body stained but faintly. The nucleus was placed eccentrically. In dried preparations the organisms were very numerous. Frequently they were encountered within the lymphoid cells and red corpuscles. In sections the parasites were so numerous that sometimes their boundaries could not be distinguished. Only the nucleus, which stained well with Loeffler's methylene-blue, could be differentiated. Accumulations of the parasites also occurred outside of the cells. They then appeared as a group of round bodies with faintly stained protoplasm and eccentrically placed nuclei. Borowsky was not successful in staining the chromatin bodies nor did he succeed in cultivating the parasite in artificial media.

Schulgin, (33) in 1902, examined fourteen cases of this disease and confirmed the conclusions of Borowsky. He believed that the parasites multiplied by division and that he could distinguish young forms of the organism in the tissues. He also suggests that the disease is conveyed by the bites of mosquitoes.

In 1903, as mentioned above, Wright, (1) in the study of a case of tropical ulcer which occurred in a child from Armenia, found certain bodies which bear a resemblance to the so-called Leishman-Donovan bodies. Wright carefully described these forms and proposed for them the name of *Helcosoma tropicum*. The organisms were generally round, sharply defined in outline, and from 2 to 4 μ in diameter. A large part of their peripheral portions was stained a pale robin's-egg blue, while their centers were unstained or white. A very prominent feature was the presence in each of the bodies of a larger and a smaller lilac-colored mass. The larger, about one-fourth or one-third the size of the body, was of variable shape but always formed a part of the rounded periphery; the smaller in some instances was round, in others rodshaped, and in the latter case was of a deeper

[6] By many observers the "*Yemen ulcer*" is regarded as identical with "Tropical sloughing phagedæna."

lilac color than the larger mass. It was usually situated near or at the blue-stained periphery of the body. The blue peripheral portions of the body were usually sharply defined from the central unstained part and sometimes showed small unstained areas. A few of the bodies were oval or elongate in form. This was thought to be due to distortion in making the preparation, because in thin sections of the tissue such forms were not apparent. In the thicker portions of the smears the central part of the bodies was stained blue as was also the periphery. These bodies were present in very large numbers in the smears, often occurring in aggregations, associated with a large nucleus, thus suggesting that they had been contained in a large cell whose outlines had disappeared in the process of fixing and staining.

Microscopical examination of paraffin sections of some of the material which had been fixed in Zenker's fluid, showed that the micro-organisms were generally closely packed together throughout the cytoplasm of large endothelial cells with single vesicular nuclei. These large cells were very numerous over extensive areas and constituted the principal part of the infiltration. The organisms occupied most of the available space between the nucleus and the cell membrane. Many of these cells contained 20 or more micro-organisms.

A portion of the lesion of the ulcer was used for the inoculation of a rabbit by subcutaneous injection and by scarification of the skin and cornea. No pathogenic effect was noted in the animal. An attempt to cultivate the organisms in freshly drawn human blood was unsuccessful.

About the same time that Wright reported the results of his study, Marzinowsky and Bogrow (34) (1904) described the occurrence of somewhat similar bodies in a case of *Pendjeh ulcer* from Persia. They believed these bodies to be protozoa. They were encountered in smears from the granulations at the base of the ulcers and were usually oval in form, more seldom round, measuring from 1 to 3 μ in size. They were frequently found in the protoplasm of epithelioid cells; less often they were seen free. They were not observed in red cells. In the secretions of the ulcer, or in the old or healing ulcers, the parasites were either very scanty or absent. In hanging-drop preparations the organisms within the cells were not motile. When lying free they exhibited a slight progressive motion. In staining with the usual aniline dyes the entire body became colored and the nucleus could not be differentiated. Sometimes the bodies lay singly or several were grouped together in the vacuoles of a cell. If the preparations were stained after Giemsa's method for chromatin (methylene-azure and eosin), the structure of the body was more clearly differentiated. The entire body was stained blue, showing two particles of chromatin (macro- and micronucleus). The first, a larger mass, was rounded and stained light blue; the second colored more deeply (red-lilac) and usually appeared in the form of a rod; it was rarely spherical in outline. This latter body, when rod-shaped, lay either perpendicular or parallel to the more lightly stained chromatin mass. In some of the forms only this rod-like particle of chromatin was stained. Attempts to cultivate the organism in various culture media failed. Experiments in the inoculation of rabbits and guinea pigs were also unsuccessful.

Plehn, (4) during the present year, has described in detail the lesions from a case in which the sore was contracted in Mesopotamia or south Persia. The epidermis over the lesion was unchanged. Upon microscopical examination, everywhere in the neighborhood of the area in which cell infiltration occurred, but here only and with increasing density toward the surface, could be seen, with a moderate magnification, collections of rounded bodies, measuring from 1 to 1.5 μ in diameter and lying between the round cells. With a higher power (apochromatic one-twelfth, compensation ocular 8–12) it could be observed that

these bodies were partly inclosed in epithelioid cells, the nuclei of which sometimes appeared to be pushed to one side. In other places, where they apparently were not enveloped in cells, the bodies lay in groups in such a manner that one might believe that they were lying inclosed in the same envelope, but that optically the latter could not be distinguished. The bodies themselves existed, first, as a deeply stained round or more elongated chromatin granule; and secondly, one about double the size, seldom three times as large, and of a somewhat different appearance. This second body probably representated a protoplasmic form, which in the central portion was lightly stained and at the margins was more deeply colored, so that sometimes a ring form resulted, at the periphery of which the deeply stained round body was situated. In a favorable light not infrequently there could be seen a second, very small, deeply stained round or more elongated granule, which either was attached to the larger one or which also appeared in the periphery of the ring, opposite to the larger body. The entire form sometimes seemed to be inclosed in a round or oval halo, which was either stained or remained uncolored.

Plehn remarks that, as the description demonstrates, the similarity of these forms to Leishman's bodies is very great; at any rate, we have to do with the occurrence of protozoa in *Oriental boil*, and the peculiar nature of these organisms makes it probable that they are the specific cause of the disease.

James (3) (1905) has very recently examined 18 cases of "*Delhi sores*" and found, in all of these, peculiar bodies which he believes to be parasites. The bodies were found within large endothelioid cells and under a low power appeared as micrococci in the protoplasm of the cell. A large number were also scattered through the films or sections, which were not inclosed in cells. When examined under a high power, these bodies, which resembled micrococci, possessed a very definite appearance and structure. Most of them were then seen to be oval in shape, but slightly broader at one end than at the other. However, a good many were quite round and some were pointed at both ends. The bodies varied considerably in size, but the length of the majority was about one-half the diameter of a red corpuscle. Their circumferences were remarkably regular and distinct, as if they were provided with a definite capsule. The greater portion of their substance stained a light blue, but near the center there was a large unstained area, sometimes divided into two by a streak of blue-stained body substance. In the interior of each body two masses of chromatin were seen. One of these was large in size, more or less rounded in shape, and was usually situated near the center, but always touching one edge of the circumference. The second chromatin mass varied in shape from a dot to a comparatively long, thick rod. In the latter case it usually lay near the center and at right angles to the long axis of the parasite. It stained more deeply than the large chromatin mass. In some parasites James saw a third, rod-shaped mass of chromatin, usually situated near the more-pointed end of the former and at right angles to the second. This was present in only a few of the bodies in each film.

On the other hand, several competent observers, who have carefully examined specimens supposedly of this disease, have encountered no specific parasites.

Thus Unna, (12) (1894) who made a very careful histological examination of a specimen of *Delhi boil* sent from Constantinople by During, was unable to find any bacteria or other parasitic organisms in his sections. In a section from Riehl's case he found micrococci in enormous numbers within the necrotic cell masses, but they were not intracellular as Riehl had described them to be, all of those which Unna could distinguish being intercellular. Leloir (11) after diligent search was

also unable to find any parasitic organisms in the tissues. In one section only he encountered a single diplococcus, lying free between the infiltrating cells. In 1897 Kuhn, (13) who examined a specimen of endemic boil, which also had not perforated the skin and over which both the stratum corneum and the stratum Malpighium continued uninterrupted, was unable to find any protozoon-like organisms, only large and small cocci, occurring either in chains or in clumps, and short, thick rods, being observed. Still more recently (1903) Babes, (9) in the examination of sections from a case of *Biskra boil*, was unable to discover the presence of any bacteria or protozoa. He concluded that the descriptions of the histological examinations of other observers show little which is characteristic, and that they even differ considerably from one another. Further, he believes that we must still consider the etiology of *Aleppo boil* as unknown, and that the lesions probably arise from infections resulting from insect bites or represent certain syphilitic nodules and ulcerations.

Jeanselme, (5) still more recently (1904), has made a careful study of a case of *Biskra boil* which the patient contracted in Algiers, and states that the fixation of the tissue in this case was perfect. Nevertheless, although a careful and detailed description of the histological appearances is given, no mention is made of the presence of any organism to which the origin of the boil might be ascribed.

Finally, Bently (41) who examined in Assam over sixty cases of sores and ulcers resembling *Delhi boil* never encountered any bodies which suggested protozoa.

It will be seen then from this review of the literature that, of the etiological factors which have been described for *Oriental boil* or *ulcer,* no single species of bacteria can be regarded as the sole specific cause of this disease. Doubtless, the pyogenic cocci or even varieties of the *Proteus* bacillus may have been responsible for the causation of many of the lesions, or at any rate, partly responsible for the pathological changes. Possibly, violent scratching of certain insect bites and secondary infections with such bacteria may have been the exciting agents of many of these ulcers. Finally, it is not clear that a number of the reported cases of *Delhi boil* do not really represent certain lesions of syphilis and yaws. However, on turning from this class of cases, we find that in a number of other instances organisms other than bacteria have been considered to constitute the origin of the disease. As already mentioned, Cunningham was the first to describe peculiar parasitic organisms, which he considered to be protozoa, in the lesions. Firth next reported the discovery of similar bodies and proposed the name of *Sporozoa furunculosa* for them. The encapsulated cocci of Riehl, it seems, should hardly be considered as related to the bodies described by these two observers, particularly if one recalls the examination and report which Unna has made of one of Riehl's specimens.

No further reference in the literature to the presence of protozoa in this disease is found until 1898, when Borowsky believed that he had encountered such organisms, Schulgin in 1902 confirming his results. Finally, Wright in 1903, Mazinowsky and Borgow in 1904, and James and Plehn during the present year, have all reported the occurrence in the lesions of bodies which they believe to be protozoa. The descriptions

bear a very striking resemblance to those which have been given of the Leishman-Donovan bodies. Regarding the researches of Cunningham and Firth, Wright has already remarked that we can not be sure that these observers were encountering parasites. In considering the more recent work, extending from the investigations of Borowsky to the present time, it is very difficult in some instances to determine the exact nature of the bodies encountered. While sometimes the detailed descriptions of the parasites are very definite, yet, when the drawings or photomicrographs accompanying the articles are examined, grave doubts enter as to the nature or the identity of the bodies in the particular instance consulted, with those forms described by the other observers. I believe that it will be impossible for us to elucidate this matter from a consultation of the literature only; and I therefore think it will be advantageous to have histological specimens from all of the reported lesions in which the protozoon-like bodies have been encountered examined by one thoroughly competent observer who is willing to undertake this work.

On account of the similarity of the organisms encountered in these cases of *Oriental sore* to the so-called Leishman-Donovan bodies, let us consider for a moment something of the nature of these latter forms.

THE LEISHMAN-DONOVAN BODY.

As is now well known, Leishman, (35) in May, 1903, "in making smear preparations from the spleen pulp of a case of so-called dum-dum fever, was struck by the curious appearance among the spleen cells and red corpuscles of enormous numbers of small round or oval bodies, two to three microns in diameter, which corresponded to nothing which he had previously met with or had seen figured or described. They stained faintly with methylene-blue and with hæmetein, showing with these stains a sharply contoured or oval shape, but no detailed structure; but on staining them by Romanowsky's method, they were found to possess a quantity of chromatin, of a very definite and regular shape, which clearly differentiated them from blood plates or possible nuclear detritus. This chromatin appeared in the form of a more or less definitely circular mass or ring, applied to which, although apparently not in direct connection with it, was a much smaller chromatin mass, usually in the form of a short rod, set perpendicularly or at a tangent to the circumference of the larger mass. The outline of the sphere or oval inclosing these masses of chromatin was only faintly visible by this method of staining. These little bodies were scattered freely among the cells, as a rule isolated one from the other, but here and there aggregated into clumps composed of 20 to 50 members."

Leishman was unable to say what these bodies were at the time, but later, when working with nagana, upon investigating the blood and internal organs of a white rat, dead of this disease, he found bodies practically identical in shape and staining reaction with those he had encountered in the spleen of his case of dum-dum fever. He concluded that these parasites were degenerated trypanosoma and that probably this particular case represented an infection with this organism.

Donovan (36) was the next one to observe these bodies, and later Ross (37) and Laveran (38) also reported in regard to the parasites. Ross inclined to the belief that they were *Sporozoa,* while Laveran, who found

them inside the red-blood cells, concluded that they belonged to the genus *Piroplasma.* Later, Marchand and Leidingham, (39) Manson and Low, (40) Bentley (41) and Christophers, (42) Castellani (43) and others, all contributed cases of dum-dum fever, kala-azar, or splenomegaly, infected with these parasites. Marchand and Leidingham inclined to the original idea of Leishman that they were of trypanosomal origin. Finally, Leonard Rogers (44) and Chatterjee (45) have stated that trypanosoma have developed in their cultures of the Leishman-Donovan bodies. These parasites have been found in the spleen, liver, bone-marrow, intestinal ulcers, lymph glands, and, according to Laveran and Donovan, within the red-blood cells.

As we have seen, similar, if not identical, forms have been encountered in a number of cases of *Oriental sore.* And in addition Donovan and Christophers have found these bodies in small and large ulcers of the skin in cases of tropical splenomegaly; though Christophers emphasizes the fact that he never detected these bodies where there was no general infection with the parasite.

After carefully perusing all the articles of the various observers on this subject, and particularly on comparing their different illustrations, the questions arise: Are the bodies described in all cases of tropical splenomegaly, *kala-azar,* and *Delhi sore* identical, and what is their origin and nature? Are they forms of trypanosomata; or are they piroplasmata or sporozoa, or some other form of parasitic life? These questions we are not at present in a position to answer. However, had good photomicrographs been prepared in all cases, as in Wright's report, the solution of some of these problems might have been made easier.

NATURE AND RELATIONSHIP OF THE BODIES ENCOUNTERED IN ORIENTAL SORE.

Wright, in his paper, makes no comment upon the question of the relation between his bodies and those described by Borowsky in 1898 and Schulgin in 1902. One can not be sure that they all were encountering the same forms. Leishman's paper appeared in 1903, after the publication of Borowsky's and Schulgin's articles, and doubtless after Wright's report had left his hands. Marzinowsky and Bogrow in their consideration of the subject, are not entirely convinced that Borowsky and Schulgin really encountered parasites in their cases. The latter authors described forms within the red-blood cells which Marzinowsky and Bogrow did not observe. However, they consider their organisms to be identical with those which Wright described, and they believe that, while the bodies they encountered were probably related to the trypanosomata, they showed noteworthy differences from them. From a comparison of the photomicrographs of the two articles, it is difficult for me to be sure that the bodies described by Wright and those by Marzinowsky and Bogrow are really

identical. Plehn considers that, if the parasites encountered in *Oriental sore* have any relation to trypanosoma, this has not yet been demonstrated.

Christophers, James, and also Rogers conclude that the organisms found in *Delhi sore* can not be distinguished by microscopical examination from those obtained from the spleen and other organs in certain cases of splenomegaly and *kala-azar*. However, James adds that since, on the other hand, the parasites met with in the Punjab are apparently capable of producing only the comparatively mild local disease known as *Delhi sore,* while those in Assam cause only the dangerous general affection known as *kala-azar,* many interesting questions are raised; as for example, whether the parasites of *Delhi sore* and of *kala-azar,* though obviously belonging to the same class, are of different species. He further believes that the evidence adduced points to the fact that, even when numerous parasites are present in *Delhi sore* on the skin for a long period, no general disease, such as *kala-azar,* results.

The parasites which I have encountered and described in the first case are clearly not identical with Wright bodies, as may be seen by comparing Wright's photomicrographs with those from my sections. As to their nonidentity with the bodies described by Marzinowsky and Bogrow, I can not be sure, as the photomicrographs of these authors do not very distinctly picture the forms they encountered. However, from their descriptions of these bodies I would suppose them to be different. On comparing my photomicrographs with the illustrations of James, differences are also seen to exist. However, Wright's bodies and those of James would hardly be considered identical, if judgment is to be made from the illustrations. The organisms encountered in my sections simulate some of the forms occasionally seen in Leishman's specimens, one of which is illustrated in fig. 11. However, when compared with the majority of his parasites (fig. 13), one sees very striking differences. The distinctions between Wright's and Leishman's bodies are also very evident; while in specimens of the forms, which Rogers has very kindly sent me, I could not certainly identify his organisms with those of Leishman. The bodies present in my sections simulate more closely some of those pictured by Marchand and Leidingham in their recent article; but it is doubtful whether they are identical with these. Plehn's article contains no illustrations.

Christophers noted that the bodies which he encountered had a very sharp outline and seemed to possess a distinct and comparatively resistant cuticle, while James states that they appear as if provided with a definite capsule. Bently also refers to a well-marked body-wall or resistant capsule.

Allusions have already been made to the opinion of some observers, who have considered the protozoa encountered in cases of splenomegaly, *kala-azar,* and *Oriental sore* as either the developmental forms of trypanosoma or those of a closely related species, or indeed as forms of sporozoa.

Ross, (46) in commenting upon Wright's discovery, mentions that a flagellated organism, *Cercomonas hominis,* is frequently found in superficial ulcers and in the intestines, and suggests that possibly these bodies of Wright may be forms of the same organism.

There can be little doubt as to the nature of the parasites encountered in my sections. They are, I believe, forms of *Blastomyces* (*torulæ*), though they are very different from the usual species of *Blastomyces* encountered in certain human skin affections. After a careful comparison of these bodies with those which have been found in ulcerations of the skin occurring in horses in the Tropics suffering from blastomycetic infection, I believe that the parasites of the two diseases are probably identical, and, as in glanders we have a disease which is occasionally transmitted to man, so human beings may also sometimes acquire this equine blastomycosis. However, it must be admitted that, when the parasites encountered in horses are compared side by side with those met with in the human case, slight differences may be observed. The equine organisms undoubtedly can be more clearly recognized as blastomycetic forms. They are also a little larger, their average length being about 5 μ, and their capsules frequently show a double contour, which has never been observed in the human parasite. However, these seem minor differences, and the similarity between the two is sufficiently great to make one feel that, even if the organisms are not identical, they must represent closely related species.

Cultures on agar were attempted from the lesion in my patient at the time the tissue was secured, but although large numbers of the parasites were inoculated, no apparent growth took place during several months. This is another point in favor of the identity of the two affections, since the parasites found in the horse are frequently very difficult or impossible to cultivate. Although the statement is often made in the literature that *Oriental boil* is communicable to the lower animals (Manson, Scheube, and Jeanselme), and that dogs, horses and rabbits have been inoculated with the discharges from the human lesions and successfully infected; nevertheless, it seems that further confirmation of this work is necessary. I did not at the time have the opportunity of inoculating a horse with any of the material from my case; but a monkey was injected subcutaneously with a portion of the fresh granulation tissue, shaken up in saline solution; though no pathological effect resulted. However, the monkey is also frequently immune against inoculation with the material from the form of equine tropical ulceration referred to. It is perhaps possible that had I not been familiar with the appearance of the torulæ encountered in this affection of horses, I might have mistaken these forms in the human lesion for protozoon-like bodies; since so much has recently been written of the occurrence of such organisms in *Oriental boil,* and since several observers state that the organisms encountered possess a definite capsule or cuticle.

SUMMARY.

My observations have led me to conclude that a number of forms of chronic ulceration of the skin are to be encountered in Manila, among which (after excluding certain ulcerative lesions of syphilis, yaws, leprosy, and lupus) there still exist at least several types of different etiology. A somewhat rare form is evidently of blastomycetic origin, in which the torulæ encountered have somewhat the appearance of the forms which have been described in certain cases of *Oriental boil* or *sore* as species of protozoa related to the Donovan-Leishman bodies.

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ILLUSTRATIONS.

FIGS. 1 TO 10.—*Ulceration of the first type*[7] (*Delhi boil*).

Fig. 1. Section of the subcutaneous tissue, showing area of necrosis with extensive cellular infiltration and fibrin formation. In the fibrin mass just to the left of the center the parasites are very numerous.

2. A portion of the same field as fig. 1, more highly magnified. The parasites may be seen as small stained dots and oval bodies, some lying free but the majority inclosed in phagocytic cells.

3. Numerous parasites inclosed in endothelial phagocytic degenerating cells. The large phagocytic cell situated just above and to the left of the center of the field incloses a parasite showing the larger mass of chromatin and also the rod-shaped body.

4. Large phagocytic cell inclosing at least five parasites, in two of which the crescent-shaped, deeply staining mass of pigment is in focus.

5. Illustrates particularly two of the parasites not inclosed in cells, one lying almost in the center of the field and the other, a "seal-ring" form, lying below the center.

6. Single parasite with ring of chromatin to which is attached a short rod.

7. Free parasites and others inclosed in phagocytic cells.

8. Numerous parasites, many in clusters which show no stained chromatin mass in focus. The presence of considerable fibrin is evident.

9. Particularly showing single parasite in the center of the field.

10. Single parasite more highly magnified ("seal-ring" form).

11, 12. Leishman-Donovan bodies in a section from the spleen; photograph from one of Major Leishman's specimens; section sent through the kindness of Dr. Koch. The parasite in the center of each figure was selected to show the sharp outline of the limiting membrane.

13. Numerous Leishman-Donovan bodies photographed from the same specimen as figs. 11 and 12. In this photograph the stained chromatin masses are in better focus than the limiting membrane of the parasites, the latter here being indistinct, but in other portions of the section much more marked.

FIGS. 14 TO 18.—*Ulceration of the second type* (*tropical sloughing phagadæna*).

14. Gross lesion of ulceration of the second type, showing patches of pseudomembrane.

15. Section of tissue from the lesion pictured in fig. 14, showing area of infiltration, necrosis, and fibrin deposit.

16. Demonstrating area of coagulation necrosis and pseudomembrane. (Weigert stain).

17. Showing granulation tissue just below the necrotic area pictured in fig. 15 (more highly magnified).

18. Demonstrating proliferation of epithelioid cells about blood vessels.

[7] In this case the only photograph obtained of the gross lesion was one representing the scar; it is not reproduced, as it shows nothing characteristic.

FIGS. 19 TO 23.—*Ulceration of the third type (ulcerative dermatitis, Veld sore?).*

19, 20. Earlier and later gross lesions of ulceration of the third type.

21. Showing cellular proliferation about blood vessel (from unbroken nodule); the left side of the vessel wall is formed by the edge of the photograph.

22. Demonstrating character of cellular infiltration in the subcutaneous tissue (from unbroken nodule).

23. Section of tissue demonstrating early lesion, and region on the edge of an ulceration. On the extreme right of the photograph may be distinguished a small area of degeneration in the Malpighian layer of the epidermis; in the center, the infiltration of this stratum may be recognized; while at the extreme left, the partial erosion and necrosis of the epidermis is apparent.

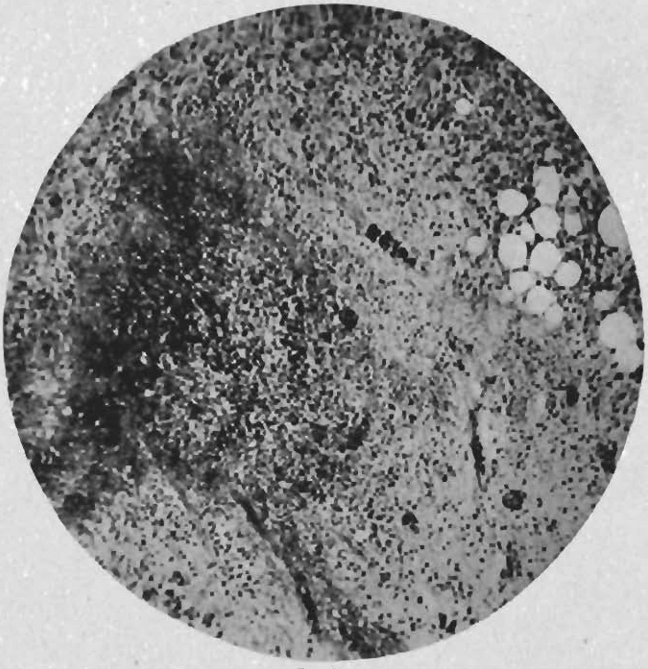

FIG. 1.

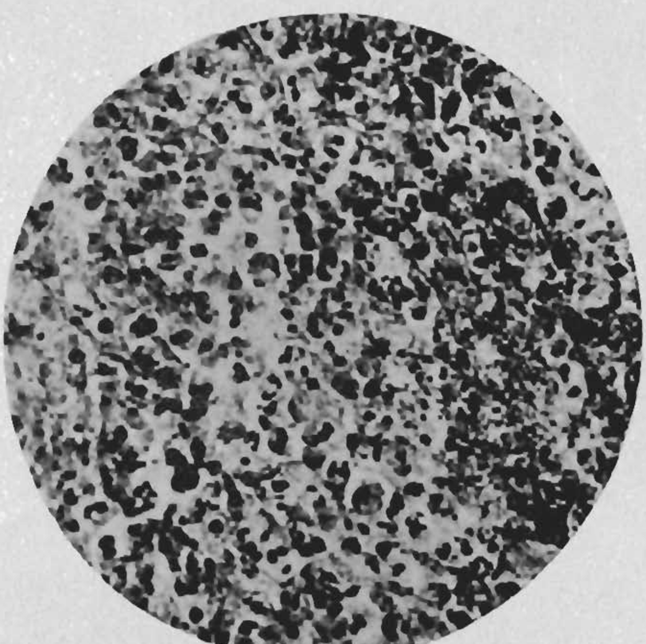

FIG. 2.

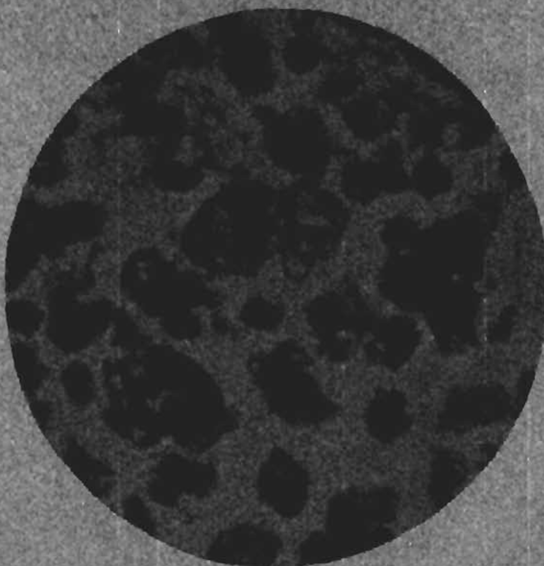
FIG. 3.

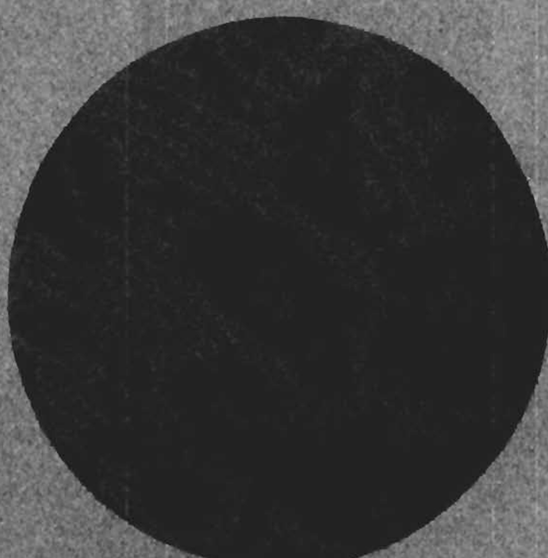
FIG. 4.

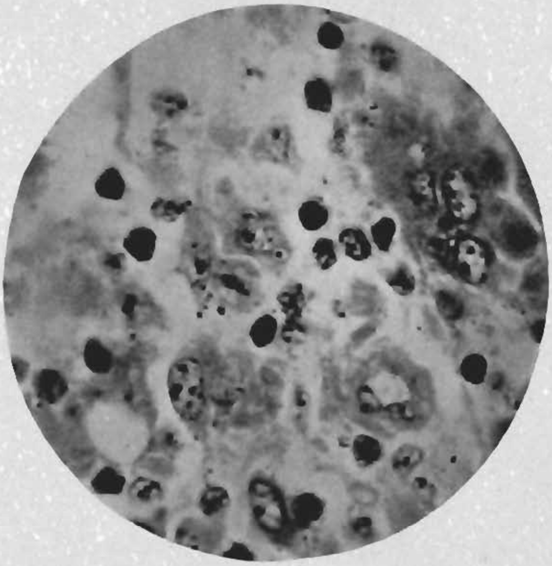

FIG. 5.

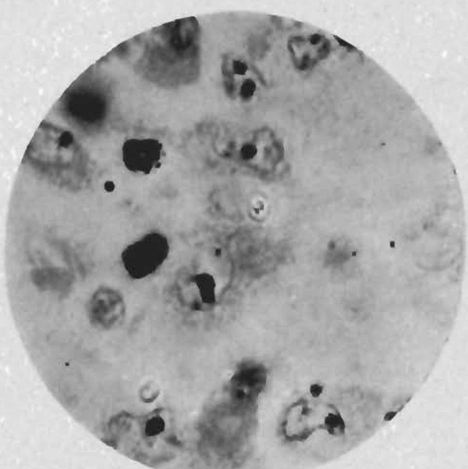

FIG. 6.

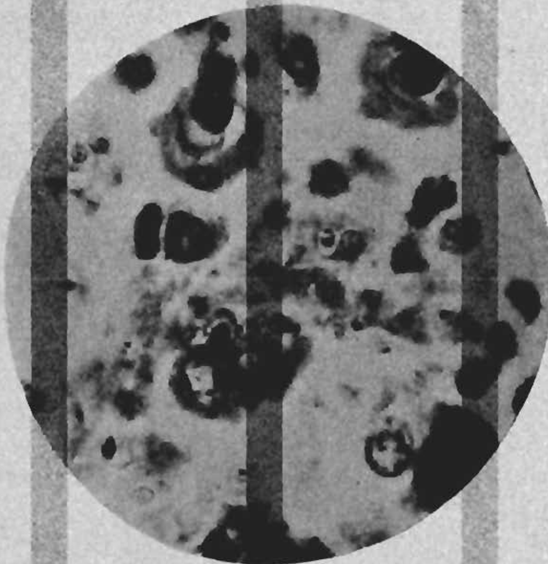

FIG. 7.

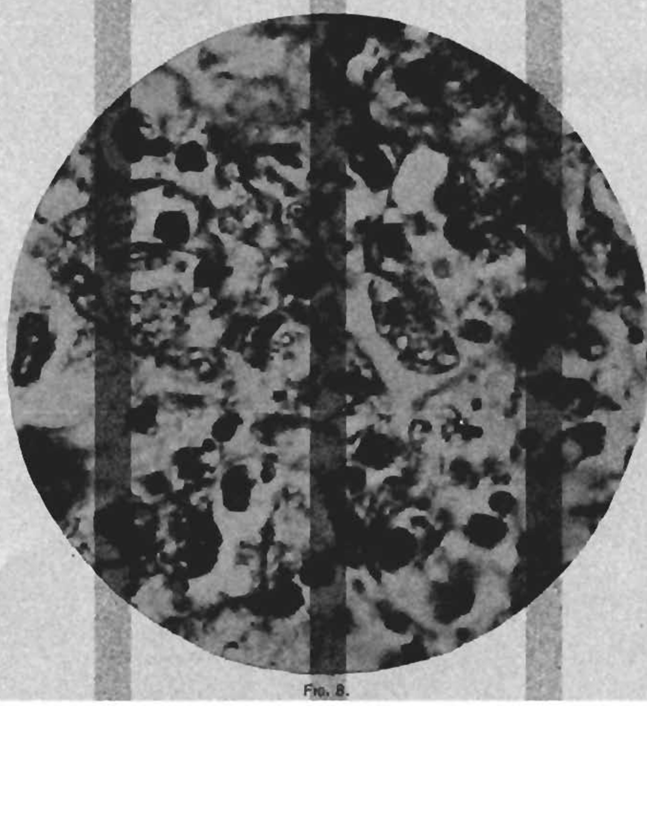

FIG. 8.

FIG. 9.

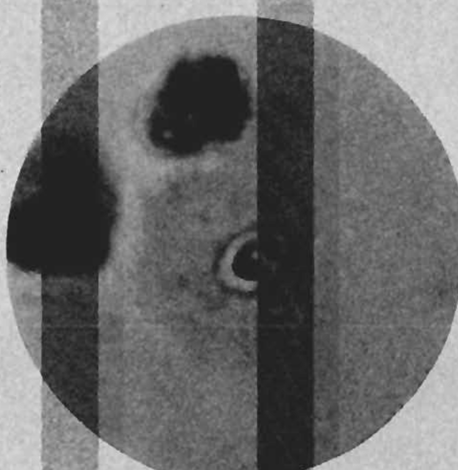

FIG. 10.

FIG. 11.

FIG. 12.

FIG. 13.

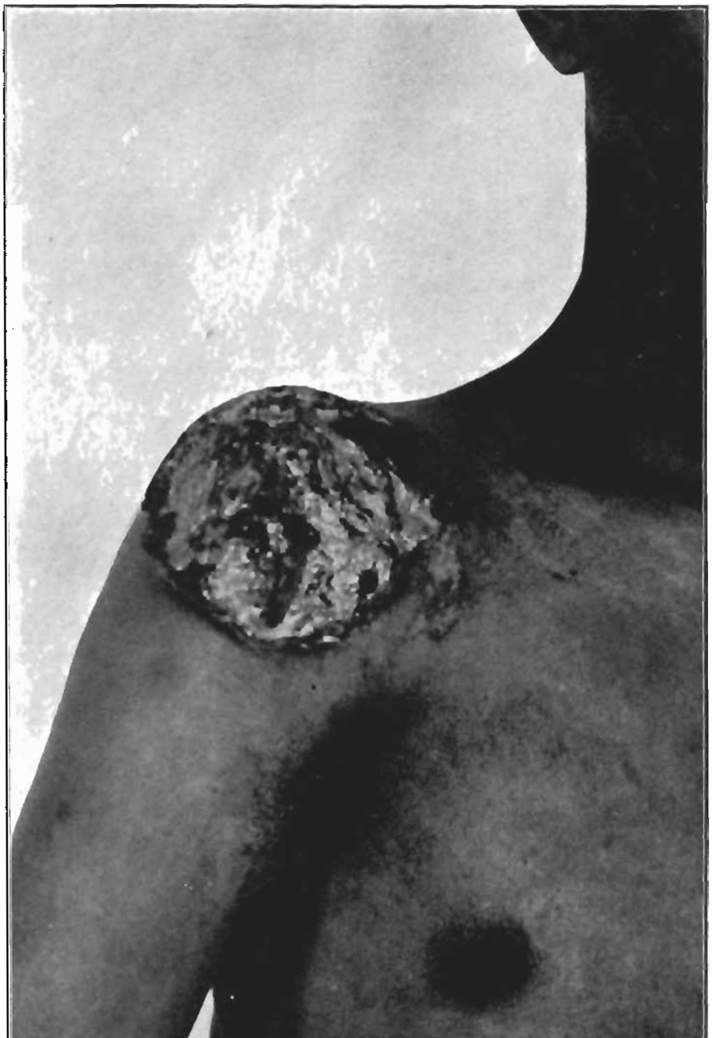

FIG. 14.

FIG. 15.

FIG. 16.

FIG. 17.

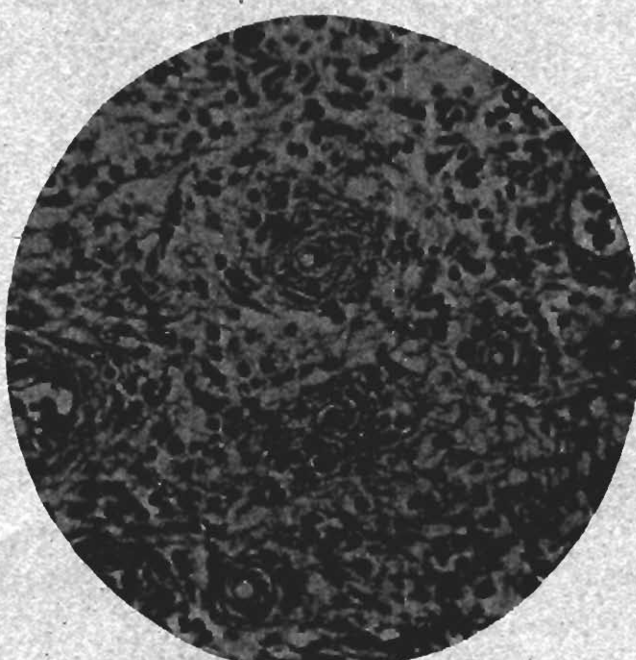

FIG. 18.

FIG. 19.

FIG. 20.

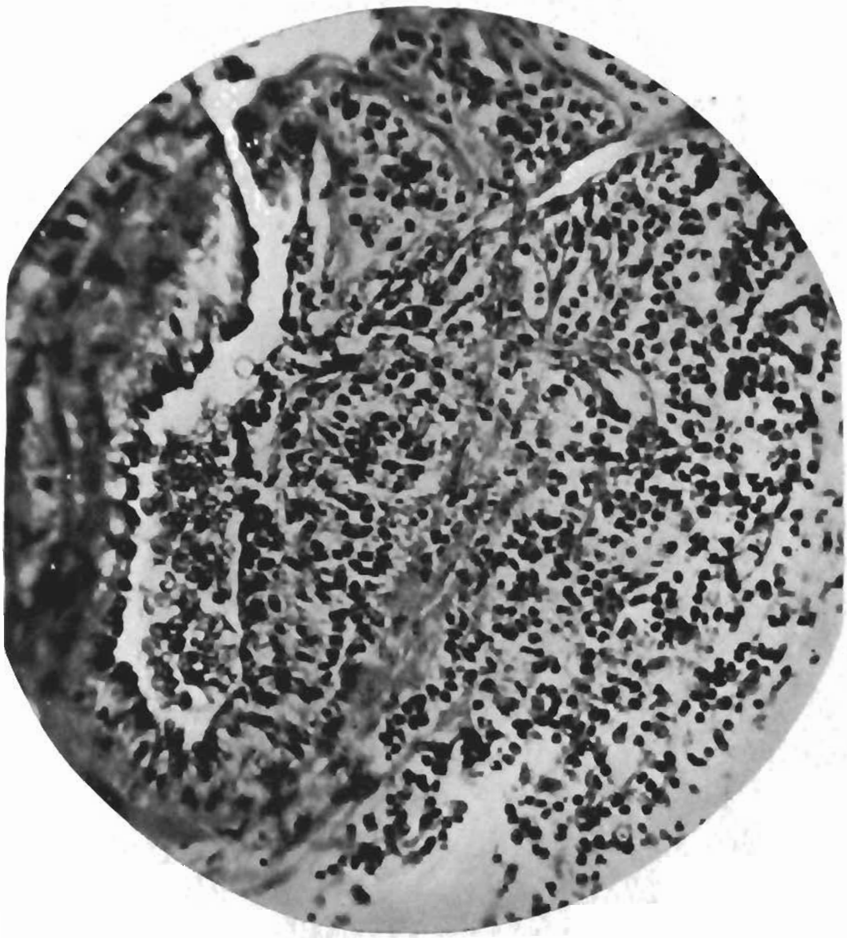

FIG. 21.

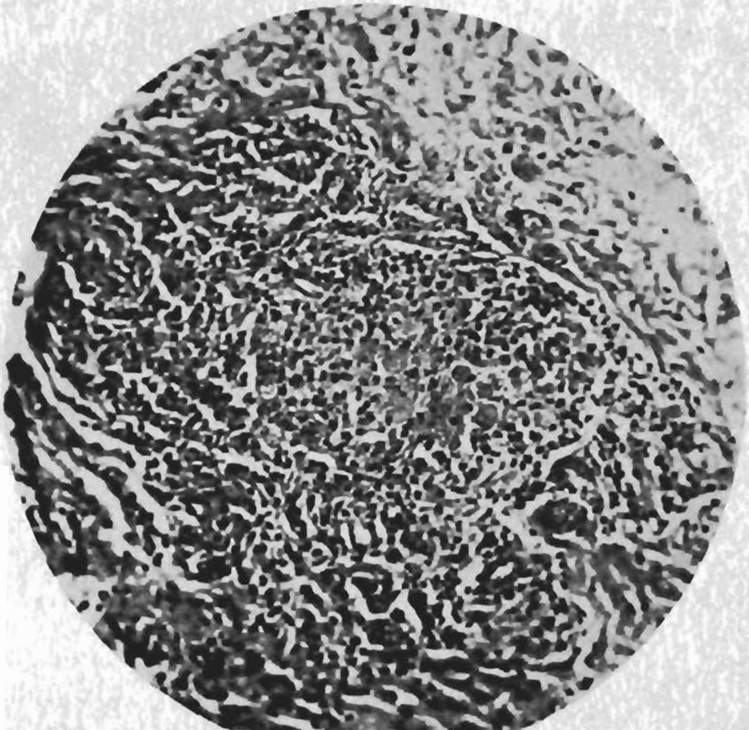

FIG. 22.